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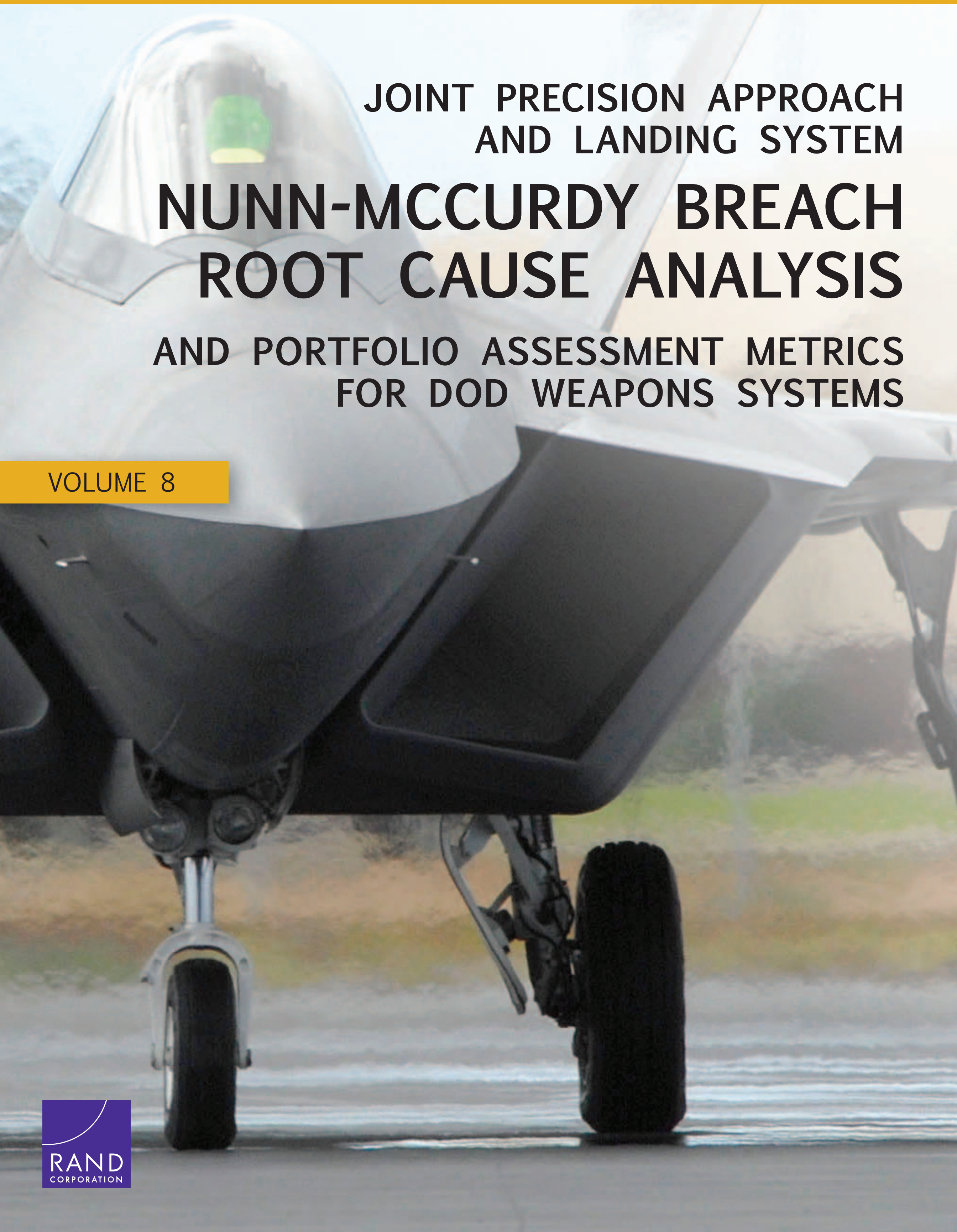
JOINT PRECISION APPROACH AND LANDING SYSTEM NUNN-MCCURDY BREACH ROOT CAUSE ANALYSIS AND PORTFOLIO ASSESSMENT METRICS FOR DOD WEAPONS SYSTEMS

VOLUME 8



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Dedication

This report is dedicated to retired Maj. Gen. Claude M. Bolton, Jr. General Bolton was a distinguished combat pilot who later headed some of the Air Force's most classified and significant programs. After his Air Force career, he oversaw Army acquisition during a time of war and change. General Bolton was an admired mentor to many pilots and military acquisition professionals. We knew him best as a consumer and reviewer of RAND research, including the work documented in this report. We often sought his advice and counsel and will miss his wisdom and collegiality.

Preface

As a result of continuing concern about large cost overruns in a broad range of major defense programs, Congress enacted new statutory provisions extending the ambit of the existing Nunn-McCurdy Act. In response to congressional direction, the Department of Defense established the Performance Assessments and Root Cause Analyses (PARCA) office to coordinate the responses to such breaches. Since then, PARCA has engaged the RAND Corporation to conduct multiple studies on the root causes of Nunn-McCurdy breaches or other large cost increases in major defense acquisition programs. In addition to reports on major defense acquisition programs, RAND, at the request of the sponsor, has researched topics related to the management of defense acquisition. This research includes such topics as program manager tenure, oversight of Acquisition Category II programs, framing assumptions, and programs with multiple Nunn-McCurdy breaches.

This report provides the results of two analyses requested by the PARCA office. One is the analysis performed by RAND on the most recent root cause analysis: the Joint Precision Approach and Landing System Increment 1A. The second analysis responds to an interest expressed by PARCA in developing a clear and replicable way to assess and summarize the overall performance of an acquisition portfolio, both at a single point in time and over several years. PARCA asked RAND for help in developing and validating a methodology that could be used by analysts within the defense acquisition community to conduct this type of portfolio assessment. The report documents the methodology RAND researchers developed in support of this request and the work they conducted to refine, validate, and demonstrate the methodology. Note that these two analyses are not analytically connected but rather represent separate responses to two requests from PARCA.

This research was sponsored by the Office of the Secretary of Defense (OSD) PARCA office and conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

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Summary

This report provides the results of two analyses requested by the Performance Assessments and Root Cause Analyses (PARCA) office. One is a root cause analysis of the Nunn-McCurdy breach by the Joint Precision Approach and Landing System (JPALS) Increment 1A program. The second analysis responds to PARCA's request for help in developing a clear and replicable way to assess and summarize the overall performance of an acquisition portfolio, both at a single point in time and over several years.

The JPALS Increment 1A Program

Background and Purpose of JPALS Program

In the early 1990s, the Department of Defense (DoD) began to pursue a precision landing system that would help in adverse weather conditions. U.S. operations in Bosnia, which were run from a relatively austere airfield with limited air traffic control capabilities and encountered recurring delays, demonstrated this need. The result was the Global Positioning System (GPS)–based JPALS acquisition program. This was an ambitious program, not only because it involved all three military services but also because it involved a civilian agency, the Federal Aviation Administration (FAA), and had international implications because many foreign airfields used the Instrument Landing System (ILS), which at the time was also the Air Force's primary landing system.

The program had three goals:

- Give U.S. forces the ability to land on an aircraft carrier's deck or a primitive airstrip in bad weather when visibility is low.
- Provide accurate information, even in the face of enemy attempts to jam the landing signal, falsify landing data, or destroy ground devices.
- Work with all Air Force, Navy, and Army platforms as well as commercial and allied aircraft.

Initially, the Air Force led the project and considered a variety of systems. JPALS was expected to cost between $1.8 billion and $3.5 billion, which would be shared

between the Army, Navy, and Air Force.[1] The Air Force led a joint military and FAA working group to study possible precision approach and landing systems, eventually concluding that no single electronic package could meet all the needs identified by the JPALS team.[2] It was finally determined that not one but two hybrid solutions would be required because DoD opposed the idea of equal military and civilian access to the GPS signal.

A number of important changes occurred during the early years of the program. These included, among others, decreased budget, technological advances, assumptions about what would be the standard precision approach and landing technology, and doubts about what technological course the FAA would follow. Eventually, the Navy assumed the lead on the program because its requirements were addressed first in the acquisition program defined at Milestone B in 2008—JPALS Inc. 1A. In January 2014, the Navy informed the Under Secretary of Defense for Acquisition, Technology and Logistics (USD [AT&L]) that the JPALS Inc. 1A acquisition program was going to have a critical Nunn-McCurdy unit cost breach.[3]

The purpose of the JPALS analysis is to identify the root cause (i.e., the underlying cause or causes of shortcomings in cost, schedule, or performance of the program) that triggered the Nunn-McCurdy breach.[4,5]

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1 "JPALS Needs Additional $12 Million for DEM/VAL, According to PBD," *Inside the Air Force*, December 20, 1996.

2 "JPALS on Tight Schedule for Improving Aircraft Approach and Landing," *Inside the Air Force*, March 14, 1997.

3 CAPT Darrell D. Lack, U.S. Navy, "Program Deviation Report Addendum for the Joint Precision Approach and Landing System Increment 1A Program," memorandum for the Under Secretary of Defense (Acquisition, Technology and Logistics), Department of the Navy, Program Executive Office, Tactical Aircraft Programs, January 28, 2014.

4 The WSARA legislation (Public Law 111–23, *Weapon Systems Reform Act of 2009*, May 22, 2009) defines root cause analysis as the following:

> (d) ROOT CAUSE ANALYSES.—For purposes of this section and section 2433a of title 10, United States Code (as so added), a root cause analysis with respect to a major defense acquisition program is an assessment of the underlying cause or causes of shortcomings in cost, schedule, or performance of the program, including the role, if any, of—
>
> (1) unrealistic performance expectations;
> (2) unrealistic baseline estimates for cost or schedule;
> (3) immature technologies or excessive manufacturing or integration risk;
> (4) unanticipated design, engineering, manufacturing, or technology integration issues arising during program performance;
> (5) changes in procurement quantities;
> (6) inadequate program funding or funding instability;
> (7) poor performance by government or contractor personnel responsible for program management; or
> (8) any other matters.

5 The National Aeronautics and Space Administration (NASA) also has defined the concept of root cause analysis given that it uses it for investigations into problems with its space vehicles, etc. In 2003, NASA defined root cause analysis as "a structured evaluation method that identifies the root causes of an undesired outcome and the

Root Cause of the JPALS Nunn-McCurdy Breach

Under current law, if a program exceeds certain cost thresholds, it is designated as having a Nunn-McCurdy breach. A breach can occur if either the average procurement unit cost (APUC) and program acquisition unit cost (PAUC) exceeds a stipulated threshold. Depending on how much the program exceeds the threshold, the breach can be classified as either significant or critical. These limits appear in Table S.1.

Both the APUC and the PAUC for the JPALS Inc. 1A program exceeded critical thresholds against both the original baseline and the current baseline triggering the Nunn-McCurdy process.[6] Table S.2, the format of which has been dubbed the "speeding ticket" for an acquisition program that breaches a threshold, shows the results in columns four and five (labeled Baseline Breached and percentage). The APUC exceeded both baselines by nearly 129 percent, and the PAUC was approximately 104 percent over both baselines. The reasons for those breaches appear in the tenth column (Cause in Source). The cause of the breach was the reduction in the number of systems, from 25 to only 17. This reduction made each system substantially more expensive.

Our analysis found that the root cause of this Nunn-McCurdy breach was the FAA's decision to continue using ILS instead of phasing it out and phasing in GPS-based precision approach and landing technology. This planning diverged from DoD's

Table S.1
Nunn-McCurdy Breach Limits

Level	Unit Cost	Baseline	Threshold
Significant	PAUC	Current	≥15%
	APUC	Current	≥15%
	PAUC	Original	≥30%
	APUC	Original	≥30%
Critical	PAUC	Current	≥25%
	APUC	Current	≥25%
	PAUC	Original	≥50%
	APUC	Original	≥50%

actions adequate to prevent recurrence" (Faith Chandler, *NASA Root Cause Analysis Supplemental Training Material, Part I: NASA RCA*, National Aeronautics and Space Administration, March 25, 2010, Foreword).

6 APUC is calculated by dividing total procurement cost by the number of articles to be procured, and PAUC is calculated by dividing program acquisition cost by the program acquisition quantity. The Nunn-McCurdy legislation established thresholds that, when crossed, require Congress to be notified. A breach can be classified as either significant or critical, depending on how much the cost exceeds the original or current baseline cost estimate of the program. For example, a PAUC that exceeds the current baseline estimate by 25 percent would be a critical breach.

Table S.2
JPALS Inc. 1A Speeding Ticket

Program	Baseline Unit Cost (FY $ millions)	Current Estimate (Source, Dec 31, 2013, SAR) FY 2008 $ millions	Baseline[a] Breached	Cost Growth Threshold Breaches: Percentage	Amount	Level	Baseline Quantity	Current Quantity (Dec 2013 SAR)	Cause in Source	Explanation in Source
JPALS Inc. 1A	APUC $8.116 (Dec 2008 APB)	APUC $18.582	Over current baseline (Dec 2013 SAR)	APUC +128.96%	+$10.466 FY 2008 $M	Critical	25	17	Reduction in total planned procurement quantities resulted in a critical Nunn-McCurdy unit cost breach to the current/original APB	As a result of the Navy's PALC Roadmap, it was determined that previously required shore-based training systems would be eliminated
	PAUC $26.032 (Dec 2008 APB)	PAUC $53.178		PAUC +104.28%	+$27.146 FY 2008 $M	Critical	37	27		
	APUC $8.116 (Dec 2008 APB)	APUC $18.582	Over original baseline (Dec 2013 SAR)	APUC +128.96%	+$10.466 FY 2008 $M	Critical	25	17		
	PAUC $26.032 (Dec 2008 APB)	PAUC $53.178		PAUC +014.28%	+$27.146 FY 2008 $M	Critical	37	27		

SOURCE: Department of Defense, *Joint Precision Approach and Landing System Increment 1A (JPALS Inc. 1A)*, Selected Acquisition Report, December 2013b.

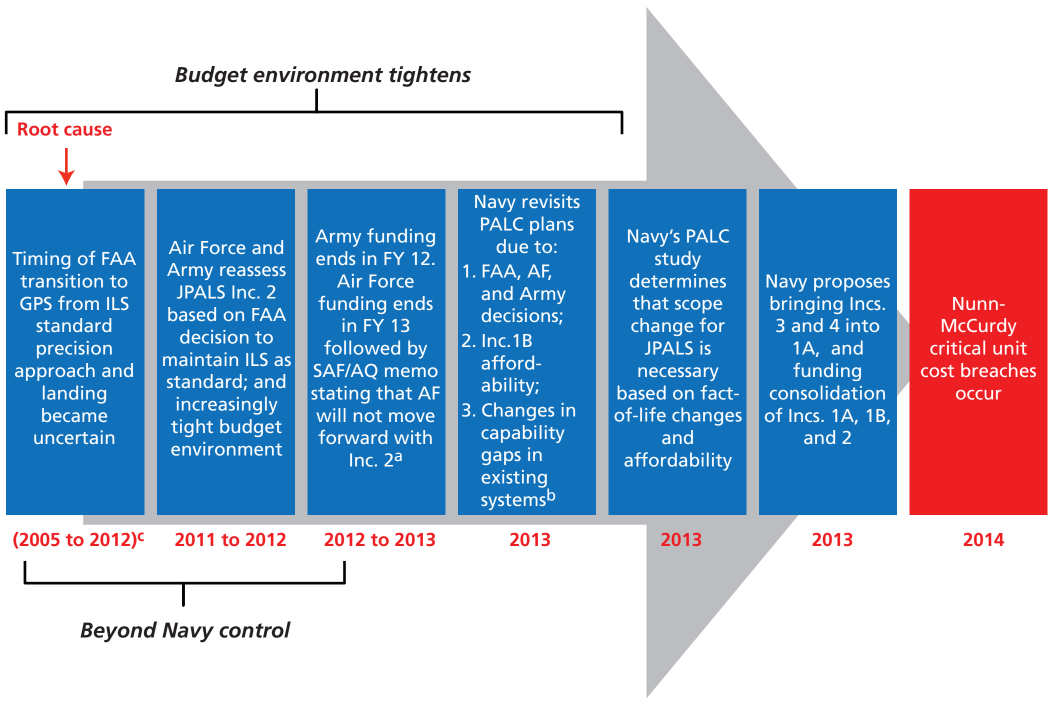
NOTE: The numbers in red indicate the "speeding ticket" triggering root cause analysis by PARCA.

[a] For the JPALS Inc. 1A program, both the original and current estimates are the same. The program had a Milestone B in 2008 in which both the current and original estimates started as the same estimate based on the APB at Milestone B. After Milestone B, there was little cost growth or other changes to the program that would have warranted a change in the current baseline; therefore, the current and original baselines remained the same until the Nunn-McCurdy breach.

plan to move toward GPS-based technology. As a result, the Army and the Air Force reassessed their precision approach and landing capability (PALC) plans and eventually pulled out of the program. The Navy then had to consider the consequences of the Air Force, Army, and FAA continuing to rely on ILS. More specifically, the Navy's proposed restructuring (and funding consolidation), which was motivated by the findings of the Navy's PALC Roadmap study, was initiated by a series of "fact-of-life" changes to the assumptions underpinning the original JPALS seven-increment plan. Figure S.1 provides the series and timing of the events discussed above.

In addition to the ultimate decision by the Navy to restructure the JPALS program, the baseline program—Inc. 1A—incurred some modest cost and schedule growth, independent of the factors affecting the Navy's decision to restructure the

Figure S.1
Root Cause of the JPALS Inc. 1A Nunn-McCurdy Breach



[a]According to a November 2012 Secretary of the Air Force for Acquisition (SAF/AQ) memo, because of recent affordability assessment, ongoing service life extension on legacy systems, and a change in operational need. The Army did not release an official memo, but zeroed out funding in April 2013 budget documents as did the Air Force. The Army has a standing unfunded requirement.
[b]A 2005 Analysis of Alternatives (AoA) identified gaps: operational interoperability with FAA, DoD, and international civil aviation organizations; supportability in all four operating environments; and an emerging gap in sea-based operations beginning in 2013 (CVN21, Joint Strike Fighter, Joint Unmanned Combat Air System).
[c]According to multiple FAA official planning documents (2001–2012), the phasedown of the standard precision and landing system, ILS, in favor of GPS-based precision approach and landing (PAL) technology did not begin as was planned in 2001. After 2008, the transition remained unclear.
RAND *MG1171/8-S.1*

program. The JPALS Inc. 1A program of record required shipboard integrated testing and operational assessment (OA). The testing was planned to occur on the CVN-77. According to the Program Deviation Report from July 2012, several shifts from 2009 to 2012 to CVN-77 installation availability occurred, delaying OA testing and consequently causing a slip in Milestone C from May 2013 to November 2013, which was an APB schedule breach. This shift also resulted in a decrease of one research, development, test, and evaluation (RDT&E) unit (from 12 to 11) and an increase of one procurement unit for a new total of 27 procurement units. The revised procurement quantity was needed to satisfy a new production schedule, which was extended by three years. The increase in procurement units and fixed costs caused an APB procurement cost breach.[7]

Using data on the program components that drove costs from each of the annual Selected Acquisition Reports (SARs), we found that RDT&E grew an additional $334.6 million because of the restructuring of the program leading to increased scope from Increments 3 and 4. Increments 3 and 4 were not fully defined, so the incorporation of these dollar values into Increment 1A introduced new uncertainty. For instance, the period of development was extended in the restructure at a cost of $215 million. New requirements associated with automatic landing capabilities increased the RDT&E costs by approximately $120 million. See Figure S.2 for an understanding of how little the program changed after Milestone B up until the Nunn-McCurdy breach.

For procurement, the cost adjustments in the SARs reveal a similar pattern, with a few costs attributable to the original scope of JPALS Inc. 1A but the majority of changes associated with restructuring the program. Contract cost growth and stretched schedule added about $19 million. Procurement decreased by $70 million because of the reduction in shore infrastructure for the reduced quantity of 10 (27 units to 17 units). Increasing the scope of the current JPALS program of record added $165 million because of shifting government staff from later increments and other small restructuring costs.

There were occasional downward cost adjustments, which are not directly connected to the root causes but are captured in the analysis process. There was almost $50 million in downward adjustments in the SARs, which includes estimating (adjustment for current and prior escalation, budget cuts from DoD and Congress). An additional $71.6 million was associated with underestimating systems engineering, integration, and testing (SEIT) in the Inc. 1A program and therefore growth in the cost of the contract. This $71.6 million is directly related to meeting the original requirements outlined in JPALS Inc. 1A.

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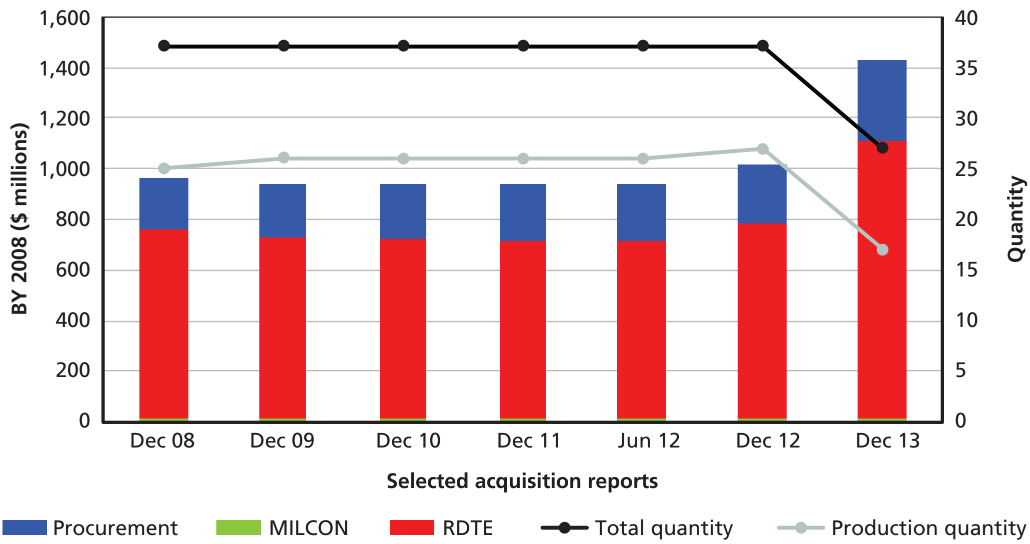
7 CAPT Darrell D. Lack, U.S. Navy, "Program Deviation Report Addendum for the Joint Precision Approach and Landing System Increment 1A Program," memorandum for the Under Secretary of Defense (Acquisition, Technology and Logistics), Department of the Navy, Program Executive Office, Tactical Aircraft Program, July 24, 2012a.

Figure S.2
JPALS Program Cost and Planned Quantity Since Milestone B, 2008 Through 2013

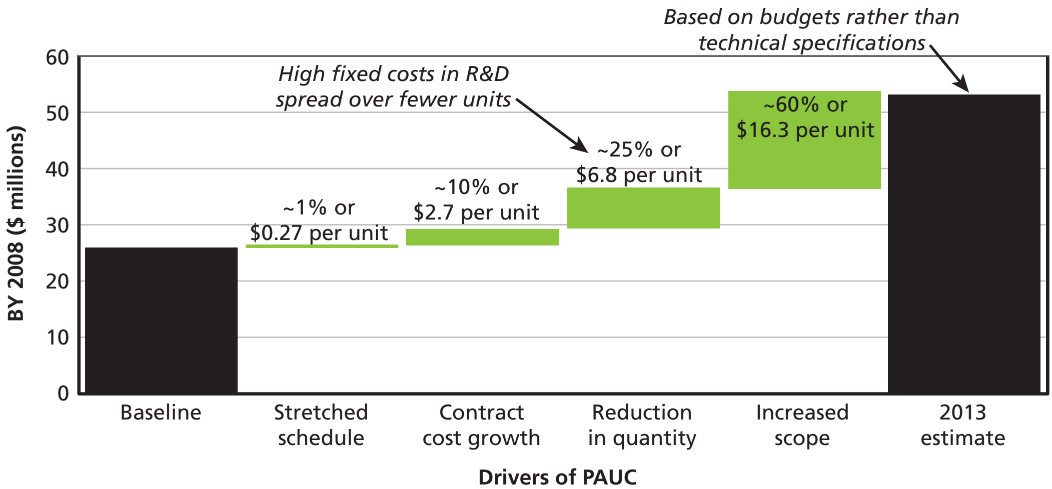


SOURCES: Department of Defense, JPALS Inc. 1A SARs, 2008 through 2013.
RAND *MG1171/8-S.2*

After categorizing the cost variances from the SARs, we summarized the cost driver effect at the unit cost level and associated a percentage with each. This gave us a better understanding of the increase in costs based on spreading those costs over fewer units. Figure S.3 reflects the analysis of the PAUC, which reinforces the notion that stretched schedule and contract cost growth are minor drivers of JPALS cost growth (approximately 10 percent), whereas the reduction in quantity and increased scope accounted for over 85 percent of cost growth.

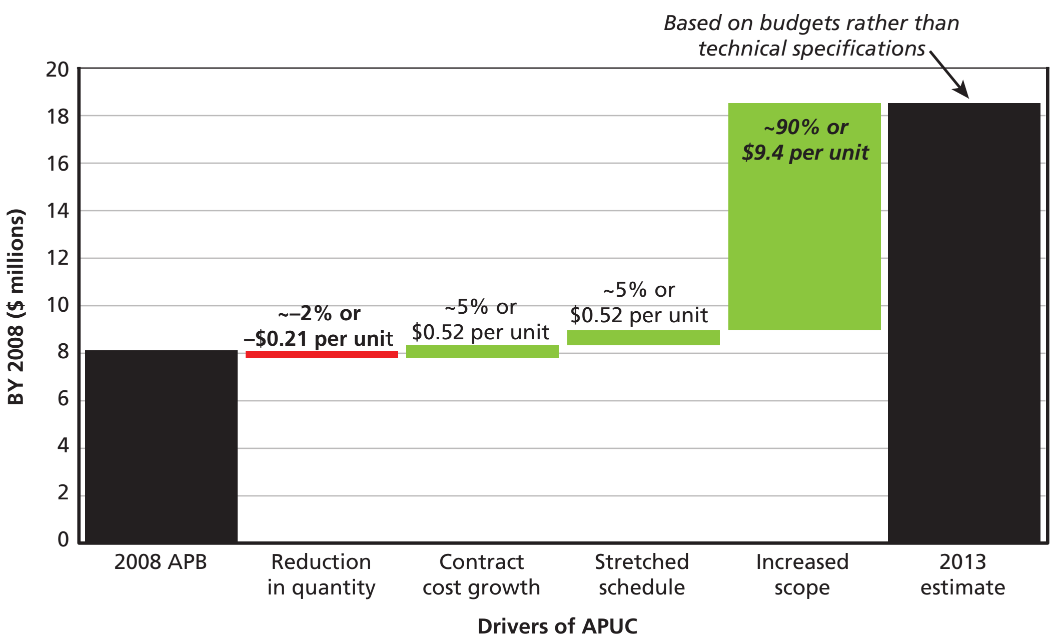
From the analysis of the APUC, it appears that the shore-based facilities that were eliminated during the restructuring may have cost more per unit than the ship-based counterpart. Therefore, the cost associated with reducing the quantity in this case is unusually negative. Of course, the smaller quantity did mean that other cost variances had a greater influence on unit cost. For the APUC, contract cost growth and stretched schedule have a minimal effect on unit cost growth. Increased scope shifted new dollars from other increments and therefore accounts for 90 percent of the unit cost growth (see Figure S.4).

Figure S.3
Major Driver Is Change in Scope, But Lower Quantity Spreads RDT&E Cost over Fewer Units in the PAUC Metric



SOURCES: RAND analysis; Department of Defense, JPALS Inc. 1A SARs, December 2009 through 2013.
NOTE: Numbers may not add to 100 percent because of rounding.
RAND *MG1171/8-S.3*

Figure S.4
About 90 percent of APUC Growth Is Driven by Increased Scope



SOURCES: RAND analysis; Department of Defense, JPALS Inc. 1A SARs, December 2009 through 2013.
NOTE: Numbers may not add to 100 percent because of rounding.
RAND *MG1171/8-S.4*

Root Cause Summary of Nunn-McCurdy Breaches

In this root cause analysis on JPALS Inc. 1A and the previous root cause analyses on other weapon systems, PARCA asked RAND to investigate the main causes of Nunn-McCurdy breaches. RAND discovered that breaches most frequently occur in the following three areas: planning, changes in the economy, and program management. Tables S.3, S.4, and S.5 provide previously identified causes of Nunn-McCurdy breaches along with JPALS Inc. 1A causes. In those tables, X indicates a cause of a breach.

Assessing the DoD Acquisition Portfolio

For purposes of oversight, planning, and decisionmaking regarding development and procurement, policymakers and leaders of the defense acquisition community need to be able to describe and assess the status and performance of portfolios of major defense acquisition programs (MDAPs) over time. We use the term *portfolio* to refer to a set of acquisition programs that can be grouped together because they share a certain characteristic or several characteristics. For example, the helicopter portfolio is a set of all helicopter programs. Portfolios can be designed and constructed in any number of ways depending on the interests of analysts. For instance, portfolios might be based

Table S.3
Root Causes Stemming from Economic Changes

Root Cause	WGS	Apache	DDG-1000	JSF	Excalibur	Navy ERP	JTRS	JPALS Inc. 1A
Increase in component costs	X	X	X	X	X			
Increase in labor costs		X		X	X			
Discontinued/decreased production of components	X							
Decreased demand for similar technology in private sector (economies of scale)	X							
Decreased demand for a technology in public sector								X
Inflation	X	X	X	X				
Production delays	X		X	X			X	
Increase in procurement quantities	X	X				X		
Decrease in procurement quantities			X	X	X			X

Table S.4
Root Causes Stemming from Planning

Root Cause	WGS	Apache	DDG-1000	JSF	Excalibur	Navy ERP	JTRS	JPALS Inc. 1A
Underestimate of baseline cost	X	X	X	X		X		
Underestimate of SEIT								X
Ambitious scheduling estimates			X	X		X		X
Poorly constructed contractual incentives	X			X		X		
Integration of new technology with legacy systems								X
Immature technologies		X	X	X			X	
Ill-conceived manufacturing process			X					
Unrealistic performance expectations			X		X	X		
Delay in awarding contract			X			X		X
Insufficient RDT&E	X	X	X	X			X	X

Table S.5
Root Causes Stemming from Program Management

Root Cause	WGS	Apache	DDG-1000	JSF	Excalibur	Navy ERP	JTRS	JPALS Inc. 1A
Unanticipated design, manufacturing, and technology integration issues		X	X	X		X	X	
Lack of government oversight or poor performance by contractor personnel			X	X				
Inadequate or unstable program funding	X	X	X	X	X	X		
Unavailability of test assets								X
Joint status of program (e.g., management complexity, budgeting complexity, and multi-service/external to DoD commitments)								X
Accounting artifact	X							

on the types of programs listed in the Defense Acquisition Management Information Retrieval (DAMIR) information system (all force application or logistics programs, for example). Or they might be based on the agency or service that owns the program. Such portfolios would include all Army, all Navy, or all DoD programs. Another type of portfolio might be constructed around individual contractors, with each portfolio including all the programs currently managed by key DoD contractors. Finally, a portfolio might be organized to include all programs at certain points in the program life cycle, past Milestone C or approaching Milestone B, for example.

We also refer to subportfolios, which include smaller sets of MDAPs with similar characteristics. The analysis of subportfolios enables us to study the status of these smaller sets of programs in more detail and to separate their status from the status of the overall portfolio of MDAPs and the status of other subportfolios.

In assessing a portfolio, analysts may need to evaluate the maturity, unit cost growth, or schedule performance of a set of programs and then summarize the status of these programs using clear and easy-to-understand metrics and visualizations. Analysts may also be interested in how a portfolio's performance changes over time, how its performance compares to other portfolios, and even how the composition of the portfolio itself may be evolving (e.g., which programs have been completed or cancelled and which are still ongoing).

The analytic approach described in this report presents a methodology and set of metrics that can be used to characterize the status and risk of portfolios of MDAPs over time and across commodity types. This type of summary, portfolio-level assessment, differs from a program-level analysis, which would focus solely on a single program and its specific performance and challenges. A summary analysis can provide a broader insight into the performance of a set of acquisition programs, its current status, future risks, and overall performance trends. It can also identify programs and portfolios that are at risk, that need additional investment, or that are performing particularly well. A portfolio-level assessment can also help acquisition analysts understand the ways in which a given portfolio may be at risk.

Developing a Methodology

The methodology that we developed for portfolio assessment included the following steps: identify objectives, choose a portfolio type, select data and metrics, address data anomalies and challenges, calculate metrics, and visualize metrics. The first step, identifying the objectives of the portfolio analysis, lays the foundation for the assessment itself and involves defining the specific set of questions that the assessment should answer. These questions are likely to reflect both the analysts' interests and policymakers' priorities.

Once the objectives of the analysis have been outlined, the next step is to select a portfolio or portfolios for analysis. Once again, this choice is likely to respond to policymakers' interests and priorities. Attention may focus on a single problematic portfo-

lio, or it may involve a comparison of several portfolios to guide such decisions as the allocation of funds or the proper amount of oversight and regulation.

Perhaps the most important step within the portfolio analysis process is the selection of metrics and data sources to evaluate the status of the portfolio of programs. The identified objectives for the portfolio analysis should frame the selection of data and metrics to perform the assessment.

After reviewing a number of databases and data sources, the team concluded that DAMIR provided the most appropriate database for the portfolio analysis. The team also assessed various data sources within DAMIR, considering ease of access for the user set, consistency and validation of data, and the regularity of data collection and presentation. Taking these into account, the team concluded that SARs would provide the primary source documents for data inputs. Congressionally mandated, the SARs are heavily vetted and produced annually, with occasional quarterly reports.[8] When SARs are not available for active MDAP programs, the team used the Defense Acquisition Executive Summary (DAES) reports most equivalent to the December SARs of the corresponding year to fill in gaps within the data. Submitted quarterly to the service-level acquisition databases and pulled into DAMIR, DAES include not only program status and assessment information by the program managers but also independent assessments by the Office of the Secretary of Defense (OSD) and Joint staff stakeholders.[9] The team used DAMIR, SARs, and DAES for all of the portfolio cases, including the test case and the helicopter and satellite portfolios.

With data sources selected, the team moved on to the selection of metrics to include in the portfolio analysis. Our portfolio analysis objectives—identify and characterize cost and schedule risks—guided our selection of program and portfolio metrics. After considering a wide range of metrics that capture different aspects of portfolio performance, status, and risk, we agreed on a set of core metrics that met our primary objectives and that we believed were flexible and comprehensive enough to serve as the foundation for an effective portfolio analysis framework. These metrics and related outcomes and indicators are listed in Table S.6.

Our metrics can be classified into several different groups. First, we defined both program- and portfolio-level metrics. Program-level metrics are those that assess the status of a single program, whereas portfolio-level metrics summarize the status of an entire portfolio of programs. Second, we include both descriptive metrics that

[8] 10 U.S.C. §2432 outlines the requirements for SAR submissions, which are mandatory for all Acquisition Category (ACAT) I programs. Program managers, through the DAMIR SAR module application, prepare SARs. Quarterly reports are submitted as major changes are observed in programs. SARs are annual unless reporting an APB or Nunn-McCurdy breach, in which case a program submits a quarterly SAR (April June, and September). Both SAR and DAES reporting begin at Milestone B, unless otherwise initiated by the Milestone Decision Authority (MDA).

[9] DAES reporting usually begins once a program is initiated at Milestone B and ends after the program submits its final SAR. DAES is reported quarterly in three groups (A, B, and C).

Table S.6
Program- and Portfolio-Level Metrics

Program-Level Metric	Outcomes/Indicators Measured	Portfolio Metric
	Descriptive-Type Metrics	
Size of program (dollars)	Cost outcomes, political (external) and policy risk	Average, median, standard deviation in dollar value
Percentage of funds remaining	Cost and schedule outcomes, overall risk	Average, median, standard deviation in percentage of funds remaining
Percentage of time remaining	Cost and schedule outcomes, overall risk	Average, median, standard deviation in percentage of time remaining
Latest milestone Achieved	Cost and schedule outcomes, overall risk	Percentage of programs passed Milestone B, Milestone C
Percentage change in quantity	Cost outcomes,overall risk	Average, median, standard deviation "Churn": average, median, standard deviation of absolute value of percentage change in quantity Percentage of programs with a quantity change over the previous year
	Performance-Type Metrics	
Nunn-McCurdy or APB breaches	Cost, schedule, performance outcomes, political risk	Number of new breaches Cumulative total breaches Percentage of programs with at least one breach
Unit cost growth: percentage change in APUC or PAUC (current and/or original baseline)	Cost outcomes, funding risk	Average, median, standard deviation in PAUC/APUC growth from current baseline Percentage of programs with increase in percentage unit cost growth Distribution of percentage unit cost growth
RDT&E and procurement cost growth	Cost outcomes, technical and requirements risk	Average, median, standard deviation in cost growth
Percentage of KPP at or above threshold[a]	Performance outcomes, technical and requirements risk	Average, median, standard deviation of percentage KPP at or above threshold

[a] Unable to collect consistent data.

simply document the characteristics of the portfolio and performance metrics that provide deeper insight into the actual status of the portfolio on chosen dimensions. In other words, descriptive metrics provide context for the interpretation of performance metrics.

Once we defined our metrics, we next collected the data needed to calculate them, using first our test case portfolio and later the helicopter and satellite portfolios. While collecting data on the chosen metrics, we came across a number of data anomalies, including missing data, programs that split or changed with the addition

of new blocks or modifications, and programs that rebaselined during the assessment period (affecting unit cost and quantity calculations). We developed a set of assumptions to deal with each of these data anomalies and then carried these assumptions forward through the test case portfolio and then the helicopter and satellite portfolios. To maintain an auditable product, analysts performing their own portfolio analysis will need to carefully track these anomalies and the assumptions or measures they took to address these.

After collecting data on each program within our portfolios of interest, we then calculated the associated portfolio metrics. Because our intention was to develop a repeatable methodology that could be applied to portfolios of all kinds, we spent considerable time developing a generalizable computer program that can easily calculate portfolio metrics.[10] This same program can be used to calculate metrics for the satellite and helicopter portfolios and will be equally applicable to other, larger portfolios with more years of data.

As noted in Table S.6, the portfolio metrics that we calculated included mean, median, and standard deviation of such quantities as percentage unit cost growth, quantity change, total program value, and percentage of RDT&E and procurement funds remaining. We also counted the number and types of breaches and the number of programs past key points in development, such as Milestones B and C. Each portfolio metric gave us a unique window on the status of the portfolio. Furthermore, these metrics can be combined to provide a more holistic view of portfolio status.

In addition to looking at static portfolio metrics to assess the status of our portfolios in each year, we also hoped to compare across years to understand how the portfolio had changed over time. This involved not only calculating metrics but also determining whether changes we observed between years were statistically significant (meaning that we can say with some confidence, usually 95 percent, that the observed change is different from zero) and substantively meaningful (or sizable enough to suggest a meaningful change over time). To address statistical significance, we used t-tests and fixed-effects models.[11] For substantive importance, we used a measure known as

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[10] The generalized computer program was developed in STATA, a statistical package used to conduct data analysis.

[11] For the test case with only two years of data, we relied on paired t-tests for unweighted data. The paired t-test takes this program consistency into account. The t-test compares the difference between the means of the two samples (2010 and 2012) to the variance within each sample independently, taking into account the number of observations. When this ratio value is large (greater than two), then the difference between the two years is said to be statistically significant and is unlikely to be due to chance or to noise in the data. For the satellite and helicopter portfolios, however, we needed a different way to assess statistical significance because we had so many more years of data. In these instances, we conducted a number of tests. First, we used a fixed-effects model, which is able to account for program-specific characteristics (essentially includes a control variable for each program in the analysis). The fixed-effects model allows us to determine whether observed differences in portfolio performance between any two years are statistically significant, meaning that we can say with some certainty that they are different from zero or that the change is a real change in the trend and is not simply noise in the data.

Table S.7
Visualizations and Information Provided

Visualization	Type of Information Provided
Histograms and bar charts	Distribution of programs Trends in numerical metrics
Box-and-whisker plots	Medians and change over time Range and spread of data (with or without extreme values)
"Heat" map	Year-on-year changes across the portfolio for one metric More detailed view of program-level information
Bubble diagrams	Two metrics displayed simultaneously A measure of a program's "influence" in portfolio One way to visualize a weighted metric
Radar charts	Aggregate view of several different metrics at one or several points in time

Cohen's D, which also compares the difference between the means of the two sample years and the differences or variation within each year.

The final step in our portfolio analysis was the construction of visualizations that can be used to summarize each portfolio metric. Table S.7 lists the visualizations used and the information that each is intended to provide. In the report, we provide additional detail about the value and uses of each type of visualization. We included several types of visualizations because each provides a specific type of information and serves a specific purpose in the analysis. Our visualizations include those that capture a single point in time, those that compare across years, and those that capture several metrics in a single picture.

Application of the Methodology: Examining Metrics

After describing in detail our approach to portfolio analysis, we next apply the methodology to the helicopter and satellite portfolios from 2002 to 2012. Our focus remains on demonstrating and validating the methodology and the selection of metrics rather than on conducting a comprehensive assessment of the portfolio. By discussing the application of our methodology in more depth, we are able to highlight the value of metrics included in the assessment, how they can be analyzed and interpreted, and how visualizations can be used to summarize the results of the analysis. Our initial application of the methodology provides the "what" of the portfolio analysis: What are the composition, the characteristics, and the performance indicators of the portfolio? In our analysis, we focused primarily on cost and schedule performance indicators as central to our assessments of the helicopter and satellite portfolios. However, we also considered the composition of the portfolio and how it evolved over the 11-year period in our analysis, the maturity of the portfolio, and trends in Nunn-McCurdy and APB breaches. For each metric considered in the analysis, we also present and interpret

visualizations of the data. We include a number of multimetric charts that summarize performance across several dimensions simultaneously. Metrics that we considered along with a summary of their contribution to the portfolio analysis include milestones achieved, composition, program value, quantity changes, and number and type of breaches.

In addition to considering the performance of each portfolio of programs over time, we also compare the performance of the two portfolios as yet another way of highlighting how the metrics included in the analysis can be used and interpreted. The two portfolios show some differences as well as some similarities. The helicopter portfolio appears to show a gradually maturing (and possibly aging) portfolio that experiences some improvement in unit cost growth and number of breaches over the assessment period. The satellite portfolio, on the other hand, has more year-to-year changes in composition and somewhat less change in overall portfolio status over the assessment window. However, the satellite portfolio still has some programs that experience extended periods of poor performance, especially between 2007 and 2010. The most significant similarity between the two portfolios is that both seem be improving on certain metrics and at the aggregate level in recent years.

One important lesson from our application of our methodology to our two sample portfolios is the importance of viewing multiple metrics from different perspectives to better understand patterns and trends in portfolio status and future risk. Single metrics do not provide a complete picture of portfolio performance. The interpretation of performance metrics must also be done in the context of the descriptive metrics, especially awareness of programs moving in and out of the portfolio, the potential for one or two programs to dominate the results of portfolio metrics, and the size of the program and funds remaining as a measure of future portfolio risk. A second important point that should be factored into any assessment of program or portfolio performance is that the utility of the analysis depends fundamentally on the quality of the data. An assessment using data that has missing data points, errors, or other problems can produce results that are misleading and can lead to misinformed decisions.

Application of the Methodology: Assessing the Helicopter Portfolio

The analysis of our selected metrics and visualizations allows for a repeatable and auditable process to track portfolio status indicators over time or across various portfolios. Inevitably, however, a policymaker or decisionmaker will want to delve into "why" portfolio trends or patterns have emerged to adjust his or her policies or priorities accordingly and to understand whether near-term action can mitigate future portfolio risk. The portfolio analysis methodology outlined in this report can be used to answer these additional questions and guide policymaker decisions. After examining our metrics and visualizations in the context of the helicopter and satellite portfolios, we took our analysis of the helicopter portfolio one step further, offering an abbreviated example of how a complete portfolio analysis might proceed. Although we did not

conduct a comprehensive root cause analysis for each of the programs in the portfolio, we did use general root cause methods to pinpoint cost growth events for the portfolio and to identify both the individual program performance issues and external forces or trends that may have driven those events. The major categories of potential policymakers' questions include greater contextual understanding, further examination into the portfolio analysis cost and schedule risk objectives, and further potential analysis inspired by the observed trends within the portfolio analysis.

In our more detailed assessment, we delve more deeply into issues such as the reasons for changes in the portfolio's composition and maturity, the drivers and implications of rates of program spending and changes in percentage of funds remaining, possible explanations for observed changes in unit cost growth and the potential for future cost growth, the effects of rebaselines, and trends in Acquisition Program Baseline and Nunn-McCurdy breaches. Finally, we use multimetric charts to offer a more holistic assessment of the portfolio. Although our assessment of the helicopter portfolio is by no means complete, a deeper assessment of the portfolio suggests the ways in which our methodology can be used to comprehensively study a portfolio of programs and how our initial set of metrics can spawn a range of other lines of inquiry that can be used to answer policymaker questions and inform their decisions.

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JPALS Analysis

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Portfolio Methodology

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Abbreviations

AAS	Armed Aerial Surveillance
ACAT	Acquisition Category
ACLS	Automatic Carrier Landing System
ACS	Auxiliary Crane Ship
ADM	Acquisition Decision Memorandum
AEHF	Advanced Extremely High Frequency
AFROCC	Air Force Requirements for Operational Capability Council
AHE	E-2D Advanced Hawkeye
AIG	Aircraft Integration Guide
AIM	Acquisition Information Management
AIR	Acquisition Information Repository
AMF	Airborne and Maritime/Fixed Station
AMRAAM	Advanced Medium-Range Air-to-Air Missile
APB	Acquisition Program Baseline
AoA	Analysis of Alternatives
APB	Acquisition Program Baseline
APUC	average procurement unit cost
ARH	Armed Reconnaissance Helicopter
AS	Acquisition Strategy
ASD (AT&L)	Assistant Secretary of Defense (Acquisition, Technology and Logistics)

ASN/RDA	Assistant Secretary of the Navy (Research, Development and Acquisition)
ASR	acquisition stability reserve
ATNAVICS	Air Traffic Navigation, Integration, and Coordination System
AVTK	Avionics Test Kit
BY	base year
C3I	command, control, communications, and intelligence
C4I	command, control, communications, computers, and intelligence
CAAS	Common Avionics Architecture System
CAPE	Cost Assessment and Program Evaluation
CDD	Capability Development Document
CCDR	Contractor Cost Data Report
CDR	Critical Design Review
Chem-Demil-ACWA	Chemical Demilitarization-Assembled Chemical Weapons Alternatives
CNO	Chief of Naval Operations
COTS	commercial off-the-shelf
CSB	Configuration Steering Board
CV	Carrier Variant
CVN	Navy Nuclear Aircraft Carrier
CVW	Carrier Air Wing
DAB	Defense Acquisition Board
DACIMS	Defense Automated Cost Information Management System
DAE	Defense Acquisition Executive
DAES	Defense Acquisition Executive Summary
DAMIR	Defense Acquisition Management Information Retrieval
DCARC	Defense Cost and Resource Center
DDG	Guided Missile Destroyer

DH	decision height
DoD	Department of Defense
DoDI	Department of Defense Instruction
DoT	Department of Transportation
DUSD	Deputy Under Secretary of Defense
EDM	engineering development model
EMD	engineering and manufacturing development
ESG	Expeditionary Strike Group
EVA	Earned Value Analysis
EVM	Earned Value Management
FAA	Federal Aviation Administration
FAB-T	Family of Advanced Beyond Line-of-Sight Terminals
FADEC	Full Authority Digital Engine Control
FBW	Fly-By-Wire
FCR	Fire Control Radar
FMS	Foreign Military Sales
FOC	Full Operational Capability
FPIF	Fixed Price Incentive Firm
FRP	Federal Radionavigation Plan; also full-rate production
FY	fiscal year
GAO	Government Accountability Office
GBAS	Ground-Based GPS Augmentation System
GBS	Global Broadcasting Service
GEO	geosynchronous earth orbit
GNSS	Global Navigation Satellite System
GOTS	government off-the-shelf
GPS	Global Positioning System

GPS OCX	Global Positioning System Next Generation Operational Control System
HMS	Handheld, Manpack and Small Form Fit
HUD	Head up Display
IAMD	Integrated Air and Missile Defense
IBR	Integrated Baseline Review
ICAO	international civil aviation organization
ICD	Initial Capabilities Document
ICE	Independent Cost Estimate
ICLS	Instrument Carrier Landing System
ILS	Instrument Landing System
IOC	initial operational capability
IQR	interquartile range
ISR	Intelligence, surveillance, and reconnaissance
JASSM	Joint Air-to-Surface Standoff Missile
JCATD	JPALS Common Avionics Technology Development
JCIDS	Joint Capabilities Integration and Development System
JLENS	Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System
JPALS	Joint Precision Approach and Landing System
JROC	Joint Requirements Oversight Council
JSF	Joint Strike Fighter
JTN	Joint Tactical Network
JTRS	Joint Tactical Radio System
KPP	key performance parameter
KSA	key system attribute
LAAS	Local Area Augmentation System
LCS	Littoral Combat Ship

LHA/D	Landing Helicopter Assault
LHD	Landing Helicopter Dock
MLS	Microwave Landing System
MNS	Mission Needs Statement
LPD	Landing Platform Dock
LRIP	low-rate initial production
LUH	light utility helicopter
MAIS	Major Acquisition Information System
MAR	Monthly Acquisition Report
MATCALS	Marine Air Traffic Control and Landing System
MDA	Milestone Decision Authority
MDAP	major defense acquisition program
MILCON	military construction
MMLS	Mobile Microwave Landing System
MNS	Mission Needs Statement
MoA	Memorandum of Agreement
MS	milestone
MUOS	Mobile User Objective System
NAS	National Airspace System; also, Naval Air Station
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVAID	navigational aid
NDAA	National Defense Authorization Act
NESP	Navy EHF Satellite Communications Program
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
O&M	operations and maintenance
O&S	operations and sustainment

OA	operational assessment
OASIS	Organic Airborne Surface Influence Sweep
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
OT&E	Operational Test & Evaluation
OTH	over the horizon
OTS	off-the-shelf
PAL	precision approach and landing
PALC	precision approach and landing capability
PAR	Precision Approach Radar
PAR/ILS	Precision Approach Radar and Hybrid Instrument Landing System
PARCA	Performance Assessments and Root Cause Analyses
PAUC	program acquisition unit cost
PDR	Preliminary Design Review; also, Program Deviation Report
P.L.	Public Law
PLCCE	Program Life Cycle Cost Estimates
PNO	program number
PNT	positioning, navigation, and timing
POM	Program Objective Memorandum
R3B	Resources and Requirements Review Board
R&D	research and development
RDAIS	Research, Development, and Acquisition Information System
RDT&E	research, development, test, and evaluation
RMS	Remote Minehunting System
RNAV	area navigation
RVR	runway visual range
SAF/AQ	Secretary of the Air Force for Acquisition

SAR	Selected Acquisition Report
SBAS	Space-Based Augmentation System
SBIRS-High	Space-Based Infrared System–High
SBSS	space-based surveillance
SCP	Service Cost Position
SDD	System Development and Demonstration
SEIT	systems engineering, integration, and testing
SFR	System Functional Review
SM	statute mile
SMART	System Metrics and Reporting Tool
SRR	System Requirements Review
SSN	nuclear submarine
STAR	System Threat Assessment Report
STOVL	short takeoff/vertical landing
SV	satellite vehicle
TACAN	Tactical Air Navigation System
TMS	Thermal Management System
TRL	technology readiness level
TRN	Terrain Relative Navigation
TRR	Test Readiness Review
TSAT	Transformational Satellite System
UAS	Unmanned Aircraft System
UAV	unmanned aerial vehicle
UCLASS	pilotless aircraft
UK	United Kingdom
USC	U.S. Code
USD (AT&L)	Under Secretary of Defense for Acquisition, Technology and Logistics

VTUAV	Vertical Takeoff and Landing Tactical Unmanned Air Vehicle
WAAS	Wide Area Augmentation System
WGS	Wideband Global SATCOM
WSARA	Weapon Systems Acquisition Reform Act

Glossary

AMS-2100	Series 2100 Instrument Landing System (ILS); provides Category I, II, and III performance that comes in multiple configurations with a variety of antenna arrays that can be upgraded in the field.
AN/FPN-67	Fixed Base Precision Approach Radar; provides aircraft position information to aid in landing operations in adverse weather and low visibility conditions.
AN/SPN-41	Transmitting Set Used for Landing; provides all-weather instrument approach guidance from the ship and works with aircraft equipped with the AN/ARA-63 receiver group. Often used as the ship's Instrument Carrier Landing System (ICLS) to provide azimuth and elevation alignment information.
AN/TPN-31	Radar Approach Control System; used for controlling and landing fixed- and rotary-wing aircraft requirements. The only fully autonomous, ICAO/NAS-compliant system that is transportable in a single C-130 aircraft.
ASR/PAR	Airport Surveillance Radar/Precision Approach Radar; a type of radar instrument approach provided with active assistance from air traffic control. The only additional equipment need is a functioning radio transmitter and receiver.
ATNAVICS	Air Traffic Navigation, Integration, and Coordination System; consists of a radar vehicle, an operations control vehicle, and two XM1102 tactical power generator (10Kw) trailers. Used in conjunction with AN/TPN-31.
AV-8B	AV-8B Harrier II; a single-engine and fixed-wing aircraft that has vertical/short takeoff and landing.
C-2A	Grumman C-2A Greyhound; a twin-engine, high-wing cargo aircraft, designed to carry supplies and logistical support. Serves as the Navy's carrier-onboard-delivery aircraft.

CH-53K	Sikorsky CH-53K Super Stallion; a large, heavy-lift cargo helicopter currently being developed by Sikorsky Aircraft for the Marine Corps. It will be fully shipboard-compatible and capable of operating from austere and remote forward operating bases.
CVW	Carrier Air Wing; a naval aviation organization composed of several aircraft squadrons and detachments of various types of fixed-wing and rotary-wing aircraft.
DH	Decision Height; a specified height in the precision approach or approach with vertical guidance at which a missed approach must be initiated if the required visual reference to continue the approach has not been established.
E-2D	Northrop Grumman E-2 Hawkeye; an all-weather, carrier-capable tactical airborne early warning (AEW) aircraft. Provides improved battle space target detection and situational awareness.
EA-18G	Airborne Electronic Attack (AEA) Aircraft; currently being delivered to the U.S. Navy, it is derived from the combat proven F/A-18F aircraft and incorporates advanced AEA avionics, which suppresses enemy air defenses (SEAD) and nontraditional electronic attack operations.
F/A-18	F/A-18 Hornet; a twin-engine, all-weather, day or night Marine jet that can be used for fighter escort, enemy air defense suppression, reconnaissance, air control, and close air support.
F/A-18E/F	F/A-18E/F Super Hornet; a twin-engine supersonic, all-weather carrier-capable multirole combat jet. Provides enhanced interoperability, total force support for the combatant commander and for the troops on the ground.
Fk-35B/C	F-35B Short Takeoff/Vertical Landing (STOVL)/ F-35C Carrier Variant (CV); aircraft with supersonic, low-observable stealth fighters used to execute multirole missions and to support F-35 sustainment technologies.
FAA	Federal Aviation Administration; the national aviation authority of the United States. An agency of the Department of Transportation, it has authority to regulate and oversee all aspects of American civil aviation.

Fire Scout	Northrop Grumman MQ-8 Fire Scout; an intelligence, surveillance and reconnaissance (ISR) vertical takeoff and landing tactical unmanned air vehicle (VTUAV). The baseline MQ-8B can accomplish missions including over-the-horizon (OTH) tactical reconnaissance, classification, targeting and laser designation, and battle management.
FPN-62	AN/FPN-62 Radar Set; a ground controlled approach radar set that uses split elevation and azimuth antennas. The antennas are reflectors with electronically scanned phased-array feeds.
FPN-63	AN/FPN-63(V) Common Precision Approach Radar; provides talk-down capabilities to land military and civil aircraft during reduced meteorological conditions. It also provides in-garrison training for controllers and pilots in support of aircraft carrier talk-down final approach landings.
FRP	Federal Radionavigation Plan; the official source of positioning, navigation, and timing (PNT) policy and planning for the federal government.
GBAS	Ground-Based Augmentation System; provides differential corrections and integrity monitoring of Global Navigation Satellite System (GNSS). GBAS provides navigation and precision approach service in the vicinity of the host airport.
GPN-22	AN/GPN-22 PAR; radar intended for unattended use in fixed-base, high-density air traffic control system operations under all weather conditions.
GPS	Global Positioning System; a radio navigation system that allows land, sea, and airborne users to determine their exact location, velocity, and time in all weather conditions.
GRN-29	AN/GRN-29(v) Instrument Landing System; a solid state instrument landing system power supply.
H-60R/S	The Sikorsky MH-60S Knighthawk and the MH-60R Seahawk; part of the Navy submarine hunter and anti-surface warfare helicopter fleet.
ILS	Instrument Landing System; a system of transmitters that provide the lateral and vertical guidance necessary to fly a precision approach.
JPALS	Joint Precision Approach and Landing System; a GPS/Inertial Navigation System that will provide a rapidly deployable, adverse weather, adverse terrain, day-night precision approach and landing capability for all DoD ground and airborne systems.

LAAS	Local Area Augmentation System; the FAA version of the GBAS and is based on a single GPS reference station facility located on the property of the airport being serviced.
LHA/D	Amphibious Assault Ships; Navy ships that project power and maintain presence by serving as the cornerstone of the Amphibious Readiness Group (ARG)/Expeditionary Strike Group (ESG).
MK-20	Fixed-base ILS.
MK-20A	Fixed-base ILS; distance measuring system.
MPN-14K	AN/MPN-14K Landing Control Central; the radar unit is used by air traffic controllers to identify, sequence, and separate participating aircraft; provide final approach guidance, guidance through air defense corridors and zones, and coordinate identification and intent with local air defense units at assigned airports, air bases, and bare bases.
MPN-25	AN/MPN-25; systems provide a critical capability to the U.S. Air Force in carrying out its mission. The Mobile Microwave Landing System (MMLS) radiates a precision signal to guide aircraft to the runway, much like civilian instrument landing systems found at domestic airports, but its frequency and aircraft are unique.
MV-22	MV-22 Osprey; Marine Corps tiltrotor aircraft, which is designated as the "baseline" variant, is a vertical/short takeoff and landing, medium-lift assault, self-deployment, and sustained land-operations-capable air vehicle.
SBAS	Space-Based Augmentation System; the FAA has developed a Wide Area Augmentation System (WAAS) to provide accurate positioning to the aviation industry—a service that is free to all other civilian users and markets in Central and North America. This service falls into the greater category of Space-Based Augmentation System (SBAS).
SEIT	Systems engineering, integration, and testing; provides programmatic insight to optimize and integrate schedules, track technical baselines, issue tracking and resolution, test, and operations across a program.
SPN-35/41	The AN/SPN-35C/41A Aircraft Control Approach Central; an upgrade to the AN/SPN-35B that provides fleet air traffic controllers an all-weather precision approach radar system for safe landing of aircraft onboard amphibious assault ships.

SPN-42	AN/SPN-42; a computerized Automatic Carrier Landing System (ACLS) radar that provides precise control of aircraft during their final approach and landing. The equipment can automatically acquire, control, and land a suitably equipped aircraft on aircraft carriers under severe ship motion or weather conditions.
SPN-46/41	AN/SPN-46(V)/AN-SPN-41; the ACLS is a precision approach landing system (PALS) that provides electronic guidance to carrier-based aircraft and allows them to land in all-weather conditions with no limitations due to low ceiling or restricted visibility. The AN/SPN-46 is the fleet's only fully automated, all-weather approach landing aid for carrier aircraft.
TACAN (URN-25)	Tactical Air Navigation System; a line-of-sight, beacon-type, air navigation aid that provides slant range, bearing, and identification information to TACAN-equipped aircraft in determining the aircraft position.
TMS	Thermal Management Systems; used for aircraft landing on ship decks.
TPN-22	AN/TPN-22 Precision Approach Radar (PAR); a transportable, computerized, pencil beam, three-dimensional radar. The system is a track-while-scan radar used for landing tactical aircraft.
TPN-25	Air Force mobile PARs include TPN-25; a solid-state precision radar that is capable of simultaneously tracking and controlling six aircraft to a specific range.
TRN-4	Terrain Relative Navigation (TRN); used to augment inertial navigation by providing position or bearing measurements relative to known surface landmarks. A vehicle's position is estimated by comparing terrain measurements (e.g., sonar or altimeter) with a terrain map.
UCLASS	Unmanned Carrier-Launched Airborne Surveillance and Strike; a program that will develop a long duration, carrier-based UAS originally capable of operations.
UH-1Y/Z	UH-1Y Huey/Venom; a twin-engine, medium-size utility attack helicopter, part of the Marine Corps H-1 Upgrades program.
UK CVF	*Queen Elizabeth*–class (formerly the CV Future or CVF project); a class of two aircraft carriers being built for the UK Royal Navy.
WAAS	Wide Area Augmentation System; an accurate navigation system developed for civil aviation. It provides service for all classes of aircraft in all phases of flight, including en route navigation, airport departures, and airport arrivals.

CHAPTER ONE

Introduction

Background and Purpose

This combined report deals with two issues. One is an analysis of the Nunn-McCurdy breach that occurred in the Joint Precision Approach and Landing System Increment 1A (JPALS Inc. 1A) acquisition program.[1] This particularly ambitious program involved not only the Army, the Navy, and the Air Force but also civilian agencies, and it had international implications because it involved the widely used Instrument Landing System (ILS)—a system dating back to the late 1920s that relies on radio beams to guide pilots to the runway when visibility is reduced. The advent of the Global Positioning System (GPS) provided an alternative to the ILS, but developing a GPS-based system that met the needs of diverse organizations posed significant challenges.

Thus, given the challenges, the fact that a Nunn-McCurdy breach occurred is not surprising, especially since many aspects of the program were influenced by forces and factors outside the Department of Defense (DoD). That fact notwithstanding, the breach occurred and, by law, DoD had to respond. The next chapter of this report provides the root cause analysis as defined in the Weapon Systems Acquisition Reform Act (WSARA) legislation.[2]

The second topic dealt with in the report pertains to the management of acquisition programs in DoD. The high cost of acquiring major items of equipment and the cost overruns that have occurred have prompted acquisition officials to ask for a way to analyze the progress of acquisition portfolios, that is, portfolios that include several individual acquisition programs, such as helicopters or satellites. Such a methodology would enable acquisition officials to monitor such factors as cost growth. Identifying cost growth across a suite of programs might enable those involved in acquisition to take preemptive steps and avoid cost overruns. It would also enable them to identify

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1 A weapon system acquisition program incurs a unit cost growth breach when the unit cost reaches or exceeds limits or thresholds specified in federal law. Such cost growth breaches are commonly known as Nunn-McCurdy breaches, in reference to the original Nunn-McCurdy amendment, although this term does not appear in federal law.

2 Public Law 111-23, *Weapon Systems Acquisition Reform Act of 2009*, May 22, 2009.

programs that are performing particularly well, thus generating lessons that might be applied elsewhere.

Organization of the Report

The report contains two substantive parts, each with a number of chapters. Part One provides the root cause analysis of JPALS, and Part Two describes the portfolio methodology. The report has two appendixes. Appendix A pertains to the JPALS program, and Appendix B pertains to the portfolio methodology.

Part One

Joint Precision Approach and Landing System Increment 1A

CHAPTER TWO

Joint Precision Approach and Landing System Increment 1A

In January 2014, the Under Secretary of Defense for Acquisition, Technology and Logistics (USD [AT&L]) was informed by the Navy that the JPALS Inc. 1A acquisition program was going to have a critical Nunn-McCurdy unit cost breach.[1] This event triggered a statutory process mandated in the 2009 WSARA legislation to perform a root cause analysis on major defense acquisition programs (MDAPs) whose cost growth exceeds the threshold as detailed in 10 U.S. Code §2433 on Unit Cost Reporting. The JPALS Inc. 1A major weapon system acquisition program is "a Global Positioning System (GPS)–based precision approach and landing system that will replace several aging and obsolete aircraft landing systems with a family of systems that is more affordable, will function in more operational environments, and support all DoD Land and Sea Based applications."[2] This part of the report describes the JPALS Inc. 1A root cause analysis, including program background, circumstances that led to the breach, and findings and future considerations. This is not intended to be a complete JPALS Inc. 1A program history, and so it does not attempt to deal with every element of the program.[3] Rather, we have attempted to identify aspects of the program that are relevant to the explanation of the Nunn-McCurdy unit cost breaches.

Research Approach

The information used in this analysis was mostly drawn from official primary source documentation. We reviewed a wide range of documentary evidence including Acquisition Decision Memoranda (ADMs); Acquisition Strategies; Analysis of Alternatives

1 CAPT Darrell D. Lack, U.S. Navy, "Program Deviation Report Addendum for the Joint Precision Approach and Landing System Increment 1A Program," memorandum for the Under Secretary of Defense (Acquisition, Technology and Logistics), Department of the Navy, Program Executive Office, Tactical Aircraft Programs, January 28, 2014.

2 Department of Defense, *Joint Precision Approach and Landing System Increment 1A (JPALS Inc. 1A),* Selected Acquisition Report, December 31, 2012b, p. 5.

3 We have provided a table of key program events in Appendix A that provides additional program history.

(AoA); Acquisition Program Baseline (APB); Defense Acquisition Executive Summary (DAES); Selected Acquisition Reports (SARs); Army, Navy, and Air Force budget materials; cost analyses from multiple sources; and cumulative earned value management system data on the major JPALS Inc. 1A contracts. Other key information sources included Letters of Notification to Congress of the Nunn-McCurdy Breach, Nunn-McCurdy Overarching Integrated Product Team cost and management briefings, and Program Deviation Reports (PDRs). We also reviewed the Federal Aviation Administration (FAA) *Federal Radionavigation Plans* given the connection between the FAA and DoD in this acquisition program, and the Navy's Precision Approach Landing Capability Roadmap. In addition, we discussed the JPALS Inc. 1A with personnel in the program office, with service-level staffs, with the prime contractor, and with staff in the Office of the Secretary of Defense (OSD). Finally, we thoroughly searched the trade literature and Government Accountability Office (GAO) audits of the program. Sources used in this root cause analysis appear in the list of references at the end of the report. This report was vetted by, and approved for public release by, the Office of the Under Secretary of Defense (OUSD) (AT&L), the Performance Assessments and Root Cause Analyses (PARCA) office, the Naval Air Traffic Management Systems Program Office (PMA213), and senior officials.

Program Cost Growth and Certification Requirements

Unit cost growth breaches are computed using definitions, formulas, and thresholds provided in federal law. 10 U.S. Code (USC) §2432 and §2433 provide "program acquisition unit cost" and "procurement unit cost," formulas for computing unit cost growth and thresholds for incurring significant and critical cost growth breaches. Table 2.1 summarizes the unit cost threshold definitions in federal law.

Table 2.1
Breach Thresholds

Level	Unit Cost	Current Baseline	Original Baseline
Significant	PAUC	≥15%	≥30%
	APUC	≥15%	≥30%
Critical	PAUC	≥25%	≥50%
	APUC	≥25%	≥50%

Organization of Part One

Chapter Three provides an overview of the JPALS Increment 1A program. It describes the motivation for the program, the key decisions made between 1997 and 2005, and the overall goals for the program. Chapter Four then discusses the Milestone B program and the framing assumptions that underpinned the program. Chapter Five contains the root cause analysis of the program, and it points out some of the limitation of that analysis. Finally, Chapter Six provides our conclusions.

CHAPTER THREE

JPALS Increment 1A Program Overview

Defining the Need for a Precision Approach Landing System

JPALS was envisioned as a new, all-weather precision landing system to be used by the Air Force, Army, and Navy.[1] Following a recurring problem of delays in the Bosnia airlift missions in the 1990s, the Assistant Secretary of Defense for Command, Control, Communications and Intelligence directed a study to analyze existing landing technology. The Air Force asked the DoD Policy Board on Federal Aviation to study and produce a Mission Needs Statement (MNS) that would then be validated by the Joint Requirements Oversight Council (JROC).[2] The MNS was approved in August 1995 and indicated that "a need exists to provide a rapidly deployable, adverse weather, adverse terrain, day-night, survivable, and mobile precision approach and landing capability (PALC) that supports the principles of forward presence, crisis response and mobility."[3] This response reflected a broader perception that the U.S. military's post–Cold War role would evolve into that of the world's peacekeeper and would require working with and landing on commercial and foreign military fields, whose technology systems may not be compatible with U.S. landing technology.[4] The JPALS systems had the following three main priorities:

- Give U.S. forces the ability to land on an aircraft carrier's deck or a primitive airstrip in bad weather when visibility is low.
- Provide accurate information, even in the face of enemy attempts to jam the landing signal, falsify landing data, or destroy ground devices.

1 "Air Force Prepares for May 30 DAB on $1 Billion Joint Landing System," *Inside the Air Force,* April 26, 1996.

2 U.S. Air Force, Director, Operational Test and Evaluation, "FY97 Annual Report on Joint Precision Approach and Landing System," *Global Security,* undated.

3 "Final Mission Need Statement USAF 002-94 Joint USAF–USN Mission Need Statement for Precision Approach and Landing Capability," August 8, 1994.

4 "JPALS Gives Pilots Autonomous Landing Capability in Inclement Weather," *Inside the Air Force*, July 26, 1996.

- Work with all Air Force, Navy, and Army platforms, as well as with commercial and allied aircraft.[5]

Taking the lead, the Air Force initially considered a number of systems and combinations of systems, some still developmental, to satisfy these requirements and still be implemented internationally. In the international and commercial spheres, several major systems were scheduled to be phased out, and there was no consensus on what type of technology would be commercially viable. Many U.S. and European airfields used the ILS, which at the time was also the Air Force's primary landing system. However, there was discussion of possibly reducing the reliance on ILS as GPS-based precision approach systems matured. The FAA announced plans to end its use of the Microwave Landing System and considered pursuing the Wide Area Augmentation System (WAAS) and potentially the Local Area Augmentation System (LAAS).[6] However, GPS can be jammed, and pilots may not realize that their location is wrong if a malfunction occurs in bad weather.[7] Several interoperable PALC systems were identified in the FAA's *Federal Radionavigation Plans* (FRPs) that needed to be considered during planning throughout the JPALS life cycle:

> The current worldwide standard system for precision approach and landing is the ILS.[8] Ground-Based Augmentation System (GBAS) [9] will provide precision approach capability in the future. The WAAS SBAS[10] technically does not provide a precision approach capability, but provides service that is functionally equivalent to a Category I (CAT I) ILS[11] approach at airports with the appropriate infrastruc-

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5 "New Military Landing System Expected to Rely on Commercial Technology," *Inside the Air Force,* August 2, 1996.

6 "Air Force Prepares for May 30 DAB on $1 Billion Joint Landing System," 1996.

7 "JPALS Gives Pilots Autonomous Landing Capability in Inclement Weather," 1996.

8 According to the FAA, ILS is the predominant system supporting precision approaches in the United States. With the advent of GPS-based precision approach systems, the role of ILS will be reduced. ILS may continue to be used to provide precision approach service at major terminals.

9 According to the FAA, the LAAS is a ground-based GPS augmentation system being developed by the FAA. It is expected to provide the required accuracy, integrity, and availability for Category II and III (categories are explained in the footnote below) precision approaches and to increase the availability of Category I services. LAAS may be used to support parallel runway operations, runway incursion warnings, high-speed turnoffs, missed approaches, departures, vertical takeoffs, and surface operations. LAAS will also support area navigation (RNAV) operations.

10 According to the FAA, the WAAS is a satellite-based GPS augmentation system being developed by the FAA. It is expected to provide lateral and vertical navigation for all phases of flight in the National Airspace System (NAS) except Category II and III precision approaches.

11 From the Federal Aviation Administration, *Aeronautical Information Manual,* April 2014:

> The lowest authorized ILS minimums, with all required ground and airborne systems components operative, are:

ture. LPV can provide approach capability as low as a 200 ft decision altitude and ½ mi visibility minimum similar to the lowest CAT I minimums.[12]

The North Atlantic Treaty Organization (NATO), the Navy, and the Army primarily used the Precision Approach Radar (PAR) system, which was being phased out because of its manpower-intensive operation and maintenance requirements and its lack of civilian interoperability.

JPALS was incorporated into the Air Mobility Command's 1997 master plan, which indicated its goal to "embark on a 10- to 15-year effort to develop, procure, integrate, and install a replacement for ILS/PAR on the ground and in more than 10,000 aircraft."[13] The total cost of JPALS was expected to be between $1.8 and $3.5 billion and would be shared among the services.[14] The Air Force led a joint military and FAA working group to study possible precision approach and landing systems, eventually concluding that no single electronic package could meet all the needs identified by the JPALS team.[15] It was eventually determined that not one, but two hybrid solutions would be required because of DoD's opposition to the idea of equal military and civilian access to the GPS signal. This was a setback to the "joint" part of JPALS and had implications for the acquisition costs and ability to interoperate with civilian and military systems.[16]

As part of the Phase 0 "Concept Exploration," the Air Force approved an AoA in September 1997 for JPALS, which selected seven technologies to consider. Three of these technologies were selected for review in the risk-reduction phase. The Local Area Differential Global Positioning System was best suited for fixed-base and special mis-

(a) Category I. Decision Height (DH) 200 feet and Runway Visual Range (RVR) 2,400 feet (with touchdown zone and centerline lighting, RVR 1,800 feet), or (with Autopilot or Flight Director (FD) or Head up Display (HUD), RVR 1,800 feet);

(b) Special Authorization Category I. DH 150 feet and Runway Visual Range (RVR) 1,400 feet, HUD to DH;

(c) Category II. DH 100 feet and RVR 1,200 feet (with autoland or HUD to touchdown and noted on authorization, RVR 1,000 feet);

(d) Special Authorization Category II with Reduced Lighting. DH 100 feet and RVR 1,200 feet with autoland or HUD to touchdown and noted on authorization (touchdown zone, centerline lighting, and Approach Lighting System with Sequence Flashing Lights (ALSF-2)are not required);

(e) Category IIIa. No DH or DH below 100 feet and RVR not less than 700 feet;

(f) Category IIIb. No DH or DH below 50 feet and RVR less than 700 feet but not less than 150 feet; and

(g) Category IIIc. No DH and no RVR limitation.

12 Department of Defense, Department of Homeland Security, and Department of Transportation, *Federal Radionavigation Plan,* Washington, D.C., 2012, pp. 4-12 and 4-13.

13 "AMC Plan Highlights Need for Near-Term Austere Field Landing System," *Inside the Air Force,* November 8, 1996.

14 "JPALS Needs Additional $12 Million for DEM/VAL, According to PBD," 1996.

15 "JPALS on Tight Schedule for Improving Aircraft Approach and Landing," 1997.

16 "JPALS Effort Will Yield Separate Solutions for Military and Civilian Users," *Inside the Air Force,* September 26, 1997.

sion environments; the upgraded Automatic Carrier Landing System (ACLS) worked best for shipboard environments; and the Precision Approach Radar and Hybrid Instrument Landing System (PAR/ILS) was best suited for tactical backup purposes.[17] Out of these, the Local Area Differential Global Positioning System was designated the "primary alternative"; however, because JPALS will result in a family of systems, other technologies, such as the LAAS, which was being pursued by the FAA, were being closely watched as potential candidates for secondary systems.[18]

In May 1998, after the AoA was complete, the JPALS program was set to submit an Operational Requirements Document (ORD) for approval as well as to reach Milestone I and enter the next program phase of definition and risk reduction. However, the JROC review and decision was cancelled because of lack of funding, which left the program in the concept development phase.[19]

JPALS Decision Landscape (1997 and 2005)

The JPALS effort had two AoAs: in 1997 and 2005. As the funding constraint abated in 2004, the USD (AT&L) directed that the original AoA from 1997 be updated to reflect the effect of technological advances, new capabilities, and improvements to other alternatives since the original analysis. The changing conditions involved the FAA's plans for a ground-based GPS-augmentation system, the use of GPS navigation as an international standard, changes to aircraft avionics in DoD, and the increasing use of Unmanned Aircraft Systems (UAS). The outcome of the revised AoA shaped the JPALS program path going forward. The result was a joint program that needed to consider that Air Force and Army needs were currently being met by ILS and PAR, and that the Navy had capability gaps involving UAS and auto-land using GPS. In addition to DoD needs, interoperability with civil systems was considered. In late 2005, with the implementation of the Joint Capabilities Integration and Development System (JCIDS) process, the Joint Staff directed that the MNS be converted to an Initial Capabilities Document (ICD), which was approved, and the updated AoA was validated by the Air Force Requirements for Operational Capability Council (AFROCC).

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[17] "Services Seek Assistance in Planning New Precision Approach System," *Inside the Air Force,* December 19, 1997.

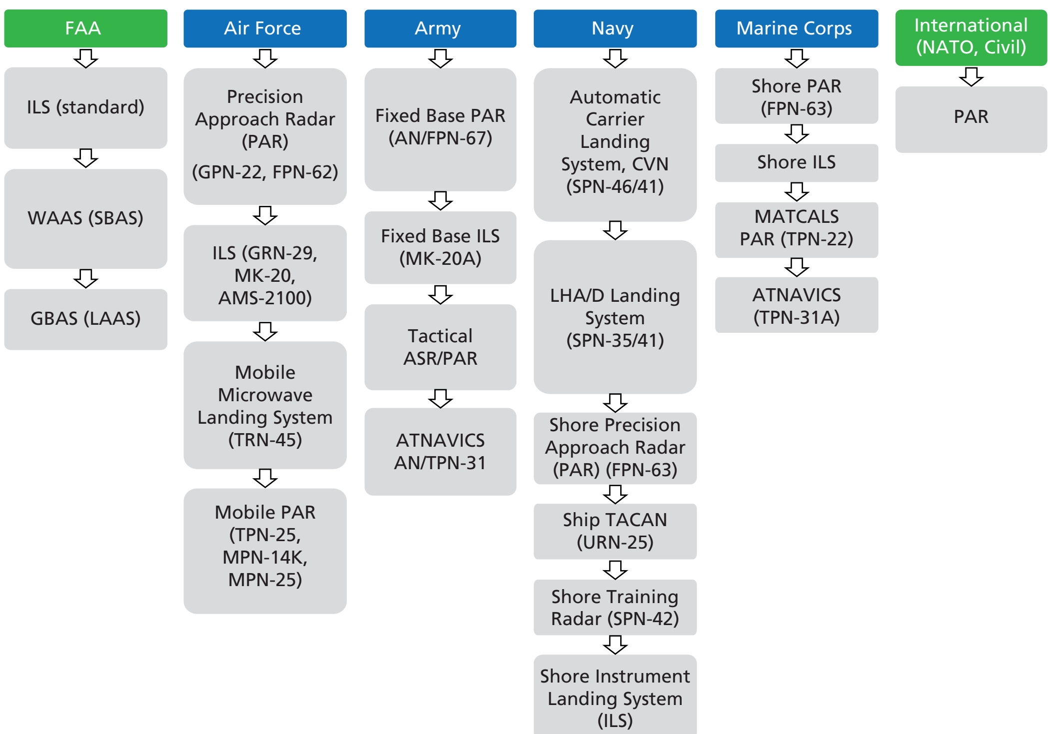
[18] "JPALS to Focus on Reducing Risks, Vulnerability of Local Differential GPS," *Inside the Air Force,* March 13, 1998.

[19] "Making Waves," *Inside the Navy,* May 18, 1998.

JPALS Goal: Interoperability Between DoD, FAA, and NATO for Precision Approach and Landing Using GPS-Based Technology

From the beginning of the JPALS effort, the Department of Transportation (DOT) (FAA) was involved because under 49 USC §101, DOT is responsible for safe and efficient transportation. The FAA is also required to develop a combined civil and military aviation system.[20] Additionally, the FAA must "select procedures, facilities, and devices that will best serve those needs and promote maximum coordination of air traffic control and air defense systems."[21] Although FAA did not fund the JPALS program, its decisions regarding PALC were considered in DoD planning.

Figure 3.1
JPALS Interoperability



SOURCE: Derived from CAPT Drew Williams, *JPALS Program Update*, Washington, D.C.: Department of Defense, Joint Precision Approach and Landing System, April 15, 2010, p. 4.
NOTES: Blue is DoD; green is non-DoD.
RAND *MG1171/8-3.1*

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[20] Public Law 85-726, 72 Stat. 737, Federal Aviation Act of 1958 (Ref. 16).

[21] Department of Defense, Department of Homeland Security, and Department of Transportation, *Federal Radionavigation Plan*, 2012, p. 1-8.

One main goal behind JPALS was to create interoperability in precision approach and landing using GPS-based technology within DoD and also with the FAA and NATO. "Civil interoperability is a 'Key Performance Parameter' to this DoD system [JPALS]. Funding and implementation of the JPALS system will be primarily dependent on moving forward with the FAA's GBAS program."[22] Figure 3.1 lists the various systems that DoD needed to take into account when designing and producing JPALS. Within this figure can also be seen the wide variety of technologies that existed in the services, FAA, and NATO regarding precision approach and landing.

22 Federal Aviation Administration, *National Airspace System Capital Investment Plan FY2013–2017*, 2011, p. 75.

CHAPTER FOUR

The Milestone B Program: JPALS Increment 1A

Following the AoA approval, the JPALS Capability Development Document (CDD) was approved by the JROC (only Increments 1 and 2 of seven were approved) in March 2007. Given the sea-based nature of the first two increments, the JROC directed the Navy to take over as lead service from the Air Force. As the program approached Milestone B, an Acquisition Strategy was approved by USD (AT&L) in July 2007. The approved JPALS Acquisition Strategy laid out a plan that consisted of seven increments, based on technology maturity and service needs. The decision was then made to separate the first increment into two sea-based phases (A and B). The JPALS Inc. 1A SAR from December 2009 provides the full listing of increments and their description (see Table 4.1). It is important to note that only the requirements for Increments 1

Table 4.1
JPALS Increments

Increment Name	Description
1A	Sea-based, ship-based systems (Navy)
1B	Sea-based aircraft integration
2	Encompasses all fixed and mobile systems that support 200 feet DH and ½ statute mile (SM) visibility that supports auto-land for properly equipped aircraft (to be executed by the Air Force)
3	Encompasses fixed and mobile systems to support FAA certification to 100 feet DH and ¼ SM visibility and a sea-based system that supports auto-land for properly equipped aircraft
4	Will provide a sea-based JPALS capability that supports 100 feet DH and ¼ nautical mile (NM) visibility, including auto-land and unmanned aerial vehicle (UAV) support
5	Will encompass land-based man-pack systems certified to minimums based on service needs
6	Will support Special Operations Forces, mobility missions, and subsequent combat operations with an autonomous approach and landing capability
7	Is an upgrade to the sea-based backup capability, involving reliability, maintainability, and life cycle improvements to the AN/SPN-41 Instrument Carrier Landing System

SOURCE: Department of Defense, *Joint Precision Approach and Landing System Increment 1A (JPALS Inc. 1A),* Selected Acquisition Report, December 2009a, p. 5.

and 2 were approved by the JROC, and the program plan that was approved for Milestone B was only Increment 1A of Increment 1.

Increment 1A had a Milestone B approval by the USD (AT&L) in June 2008. At the same time, it was designated an Acquisition Category (ACAT) 1D acquisition program.[1] The System Development and Demonstration (SDD) contract was competitively awarded to Raytheon Corporation. The losing team lodged a formal bid protest with the GAO, but it was withdrawn three months later, so the JPALS Inc. 1A program was minimally affected by the protest. An APB was formally approved in December 2008. As reported in the 2009 SAR, the mission for the approved JPALS program is as follows:

> Joint Precision Approach and Landing System (JPALS) is a program with Tri-Service partners for acquisition of JPALS including the Navy . . . Air Force . . . and Army . . . JPALS is a Global Positioning System (GPS)-based precision approach and landing system that will replace several aging and obsolete unique aircraft landing systems. JPALS will provide a family of systems that is more affordable, will function in more operational environments, and will support all…DoD Land and Sea Based applications. The National Defense Strategy of the United States of America calls for highly mobile forces that can rapidly respond to crises worldwide. Success in meeting this challenge requires the ability to land aviation assets virtually anywhere, at any time. JPALS will provide this capability by being rapidly deployable, survivable and interoperable among the U.S. Services and with U.S. allies, as well as with civil aircraft and landing facilities. JPALS will eventually support unmanned and highly automated aircraft, and will be able to operate during restricted Emission Control (EMCON) conditions.[2]

Following Milestone B, the Increment 1A program completed a series of key events before the Nunn-McCurdy breach in 2014. These included:

- System Requirements Review (SRR)-2 (January 2009)
- Integrated Baseline Review (IBR) (April 2009)
- System Functional Review (SFR) (June 2009)
- Preliminary Design Review (PDR) (December 2009)
- Critical Design Review (CDR) (December 2010)

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1 ACAT I programs are MDAPs. An MDAP is a program that is not a highly sensitive classified program and is designated by USD (AT&L) as an MDAP; or that is estimated to require eventual expenditure for research, development, test, and evaluation (RDT&E), including all planned increments, of more than $480 million (fiscal year [FY] 2014 constant dollars) or procurement, including all planned increments, of more than $2.79 billion (FY 2014 constant dollars). ACAT I programs have two subcategories: ACAT ID for which the Milestone Decision Authority (MDA) is USD (AT&L). The "D" refers to the Defense Acquisition Board (DAB), which advises USD (AT&L) at major decision points.

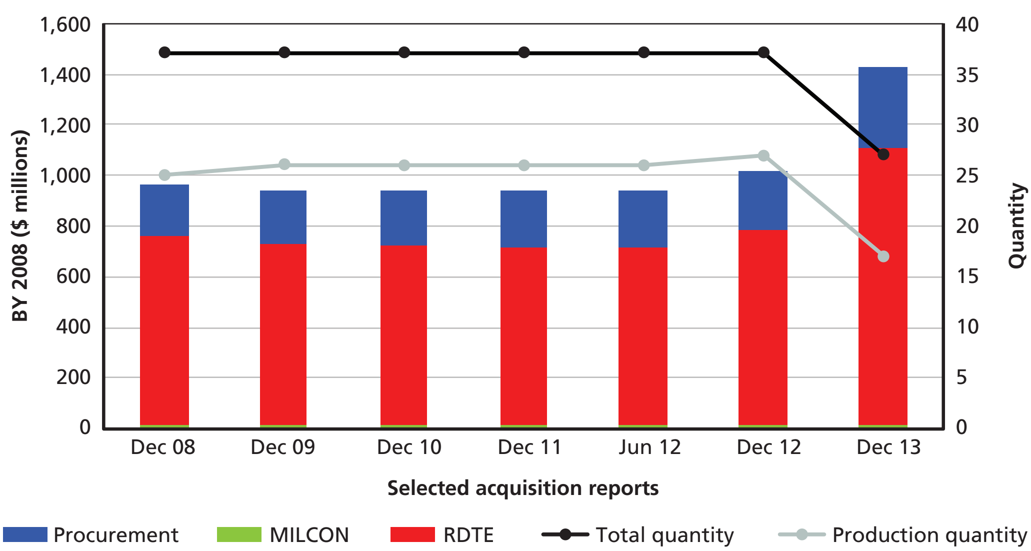
2 Department of Defense, 2009a, p. 5.

- Delivery of three engineering development models (EDMs) to the contractor system integration lab (2010)
- Completed early testing of the GPS receivers onboard Landing Helicopter Deck (LHD-1), which mitigated several program risks before the beginning of formal developmental test (July 2011)
- Test Readiness Review (TRR) (May 2012)
- Commenced Integrated Test (June 2012).

JPALS Increment 1A Program Cost and Planned Quantity After Milestone B

The JPALS program's 2008 to 2013 SARs informed our understanding of program cost and planned quantity for the JPALS Inc. 1A program. The acquisition program that was defined at Milestone B is only Increment 1A. Subsequent increments would have their own Milestone B as they are introduced. At the macro level shown in Figure 4.1, the JPALs Inc. 1A program has almost constant cost and quantity from 2008 to 2012. The majority of the program's planned spending falls under RDT&E. Procurement costs for this program were roughly 20 percent of estimated total program costs. The 2013 SAR reported the reorganization of the program. On the financial side, the reorganization involved shifting funds from future increments into the current Increment

Figure 4.1
JPALS Program Cost and Planned Quantity Since Milestone B, 2008 Through 2013



SOURCES: Department of Defense, JPALS Inc. 1A SARs, 2008 through 2013.
RAND *MG1171/8-4.1*

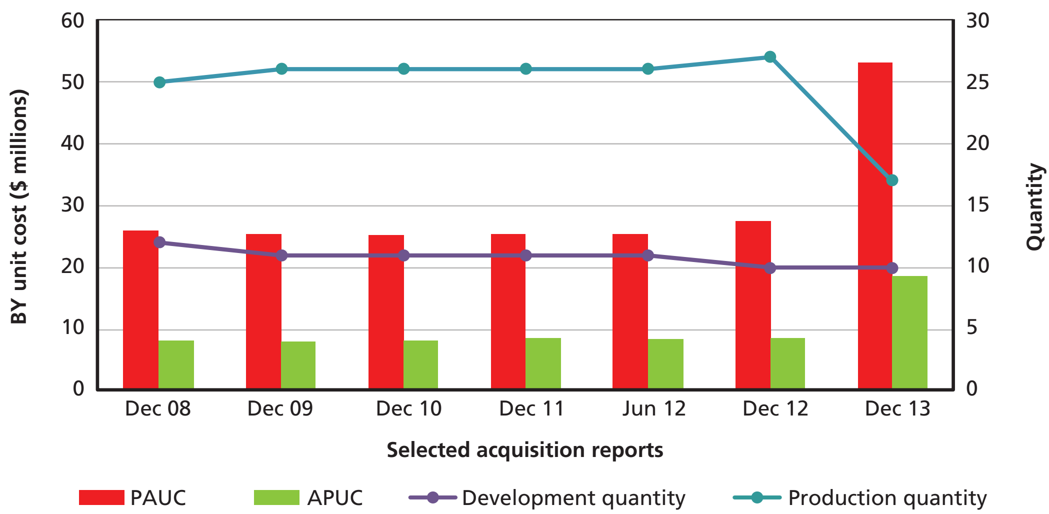
1A program and reporting in the SAR. As for quantity, there was a change in the requirement for shore-based training units prompting the decrease in 2013 as the Air Force and Army assumed less active roles in the program. Other details of the reorganization are discussed further in Chapter Five.

As quantity remained consistent between 2008 and 2012, the unit cost of the JPALS program did not change significantly until the reduction in quantity reported in the 2013 SAR (see Figure 4.2). Unit costs are measured with two congressionally mandated metrics: program acquisition unit cost (PAUC) and average procurement unit cost (APUC).[3] The majority of costs are within RDT&E, which is reflected in the PAUC. With the restructure in 2013, both PAUC and APUC exceeded the Nunn-McCurdy thresholds for cost growth.

JPALS Increment 1A Framing Assumptions

As part of our analysis of the JPALS Inc. 1A program, we collected available framing assumptions for the program and supplemented them with additional information as necessary. Framing assumptions are the foundational assumptions that underlie a program's structure and acquisition strategy and determine why critical elements of

Figure 4.2
JPALS Unit Cost and Planned Quantity Since Milestone B, 2008 Through 2013



SOURCES: Department of Defense, JPALS Inc. 1A SARs, 2008 through 2013.
RAND *MG1171/8-4.2*

[3] PAUC is calculated by dividing the program acquisition cost by the total quantity. APUC includes only procurement cost divided by procurement quantity.

a program's acquisition strategy were designed (planned) the way they were. All programs have framing assumptions, explicitly or implicitly, at program initiation. If these assumptions turn out to be incorrect, program execution can be adversely affected.[4]

As a program planning and management tool, framing assumptions should be generated at the beginning of a program and then monitored during program execution to uncover significant deviations that may adversely affect cost, schedule, and performance outcomes. However, framing assumptions can also be used as part of a root cause analysis; the exercise enables analysts to identify a small number of key assumptions that drive outcomes.

RAND identified the following framing assumptions for JPALS:

- GPS-based precision approach and landing technologies are suitable for multiple ship- and shore-based environments and aircraft. After a number of studies and limited demonstration in the early 1990s (under Air Force lead), DoD and FAA settled on a GPS-based approach to meet multiagency and international requirements for precision approach and landing capabilities. A part of this, from the DoD perspective, is the need for DoD aircraft to be interoperable with the precision landing systems of civilian airports. This assumption appears to remain valid.
- Incremental development and use of commercial off-the-shelf/government off-the-shelf (COTS/GOTS) hardware and software will lower risks. JPALS Inc. 1A is based on existing hardware. Most of the technical risk in the program revolved around development of the algorithms (software) that improve the precision of the GPS signal. Given the minimal cost and schedule growth associated with technical challenges, this assumption also appears to remain valid.
- Test assets (ships and aircraft) will be available as planned for JPALS installation, test, and integration. This is somewhat unique to Navy ships because they have very limited quantities available at any given time for operations. JPALS Inc. 1A required that EDMs be installed on CVN and L-class (Landing Platform Dock [LPD], Landing Helicopter Dock [LHD]) ships for development and operational testing. Installation and test therefore requires that the intended ship supporting the test be at its home port for sufficient time. However, the ships were not available for testing as intended, which resulted in some schedule slip and a need to adjust the test program to meet these realities.
- FAA and DoD investment needs and time frame for technology transition are similar. In particular, the original structure of the JPALS program (to include at least Incs. 1A, 1B, and 2) was based on the assumption that the FAA would

[4] Mark V. Arena, Irv Blickstein, Abby Doll, Jeffrey A. Drezner, James G. Kallimani, Jennifer Kavanagh, Daniel F. McCaffrey, Megan McKernan, Charles Nemfakos, Rena Rudavsky, Jerry M. Sollinger, Daniel Tremblay, and Carolyn Wong, *Management Perspectives Pertaining to Root Cause Analyses of Nunn-McCurdy Breaches, Volume 4: Program Manager Tenure, Oversight of Acquisition Category II Programs, and Framing Assumptions,* Santa Monica, Calif.: RAND Corporation, MG-1171/4-OSD, 2013.

begin transition from legacy ILS to GPS-based systems in 2010 time frame (see the discussion of FAA decisionmaking below). This turned out not to be the case.
- The Air Force, Army, and Navy will remain committed to JPALS as a solution to precision approach and landing interoperability. When the FAA kept ILS operational and deferred transition to a GPS-based technology, the need to equip legacy DoD aircraft with JPALS disappeared or moved to the out-years. Most of the Air Force and Army fleet already had ILS and so did not have the same capability gap that many Navy aircraft had without ILS.

The JPALS framing assumptions are consistent with both the 2005 AoA and the Navy's 2012–2013 assessment of changing conditions. Changes in these assumptions and changes in the environment defined by these assumptions significantly affected JPALS' decision environment, forcing the Navy (and other JPALS stakeholders in DoD) to revisit the program structure and objectives to align better with actual conditions.

CHAPTER FIVE

Root Cause Analysis

As mentioned above, the JPALS Inc. 1A program declared a Nunn-McCurdy unit cost breach in January 2014 when a program deviation report was signed by the program manager on January 28, endorsed by the Navy Acquisition Executive, and forwarded to the MDA on March 12, 2014. The Secretary of the Navy notified Congress of the breach on March 19, 2014.

Table 5.1 provides the details of the breach in what has been called the "speeding ticket" in past Nunn-McCurdy analyses performed by RAND. The speeding ticket shows that the APUC and PAUC exceeded critical thresholds against both the original baseline and the current baseline. The APUC exceeded by nearly 129 percent over both baselines, and the PAUC exceeded by approximately 104 percent over both baselines. In addition, the cost growth expressed in dollar amounts over the original or current baseline was calculated. Brief explanations of the immediate causes of the unit cost growth, as reported in the SAR, are also provided in the table.

Figure 5.1 lays out the key events that provide context within the program's life cycle and that eventually led to the Nunn-McCurdy breach. The events in red boxes are important pieces of the explanation of what happened to trigger the breaches. The decisions of both the FAA and the services are noted in the figure, particularly that the timing of the ILS phasedown became uncertain, which meant that the ILS would continue to be the standard.

Root Cause: FAA Transition to GPS-Based Precision Approach and Landing Diverges from DoD JPALS Planning

Ultimately the FAA decision to continue using ILS instead of phasing it out and phasing in GPS-based precision approach and landing technology diverged from DoD's plan to move toward GPS-based technology. As a result, the Army and the Air Force reassessed their PALC plans. The root cause of the breach lies in part on multiple decisionmakers making multiple decisions regarding the PALC that was going to be used by each entity.

The Navy then had to consider the consequences of the Air Force, Army, and FAA continuing to rely on ILS. More specifically, the Navy's proposed restructur-

Table 5.1
JPALS Inc. 1A Speeding Ticket

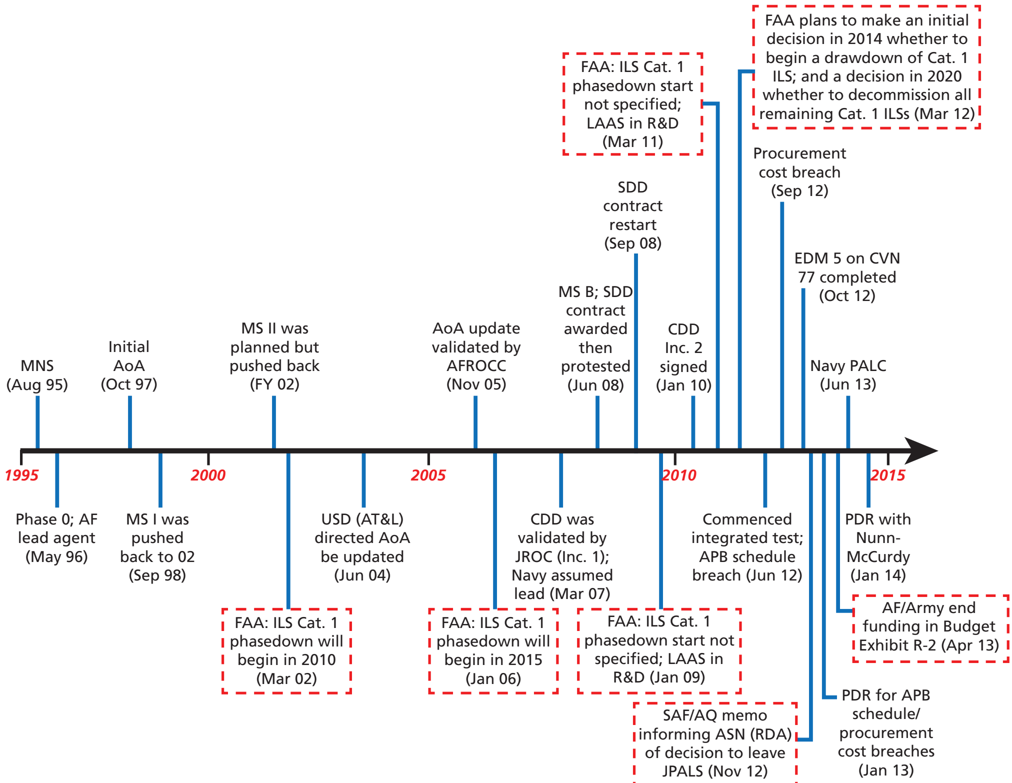
			Cost Growth Threshold Breaches							
Program	**Baseline Unit Cost (FY $ millions)**	**Current Estimate (Source, Dec 31, 2013, SAR) FY 2008 $ millions**	**Baseline[a] Breached**	**Percentage**	**Amount**	**Level**	**Baseline Quantity**	**Current Quantity (Dec 2013 SAR)**	**Cause in Source**	**Explanation in Source**
JPALS Inc. 1A	APUC $8.116 (Dec 2008 APB)	APUC $18.582	Over current baseline (Dec 2013 SAR)	APUC +128.96%	+$10.466 FY 2008 $M	Critical	25	17	Reduction in total planned procurement quantities resulted in a critical Nunn-McCurdy unit cost breach to the current/original APB	As a result of the Navy's PALC Roadmap, it was determined that previously required shore-based training systems would be eliminated
	PAUC $26.032 (Dec 2008 APB)	PAUC $53.178		PAUC +104.28%	+$27.146 FY 2008 $M	Critical	37	27		
	APUC $8.116 (Dec 2008 APB)	APUC $18.582	Over original baseline (Dec 2013 SAR)	APUC +128.96%	+$10.466 FY 2008 $M	Critical	25	17		
	PAUC $26.032 (Dec 2008 APB)	PAUC $53.178		PAUC +014.28%	+$27.146 FY 2008 $M	Critical	37	27		

SOURCE: Department of Defense, *Joint Precision Approach and Landing System Increment 1A (JPALS Inc. 1A)*, Selected Acquisition Report, December 2013b.

NOTE: The numbers in red indicate the "speeding ticket" triggering root cause analysis by PARCA.

[a] For the JPALS Inc. 1A program, both the original and current estimates are the same. The program had a Milestone B in 2008 in which both the current and original estimates started as the same estimate based on the APB at Milestone B. After Milestone B, there was little cost growth or other changes to the program that would have warranted a change in the current baseline; therefore, the current and original baselines remained the same until the Nunn-McCurdy breach.

Figure 5.1
JPALS Key Events Leading to a Nunn-McCurdy Breach

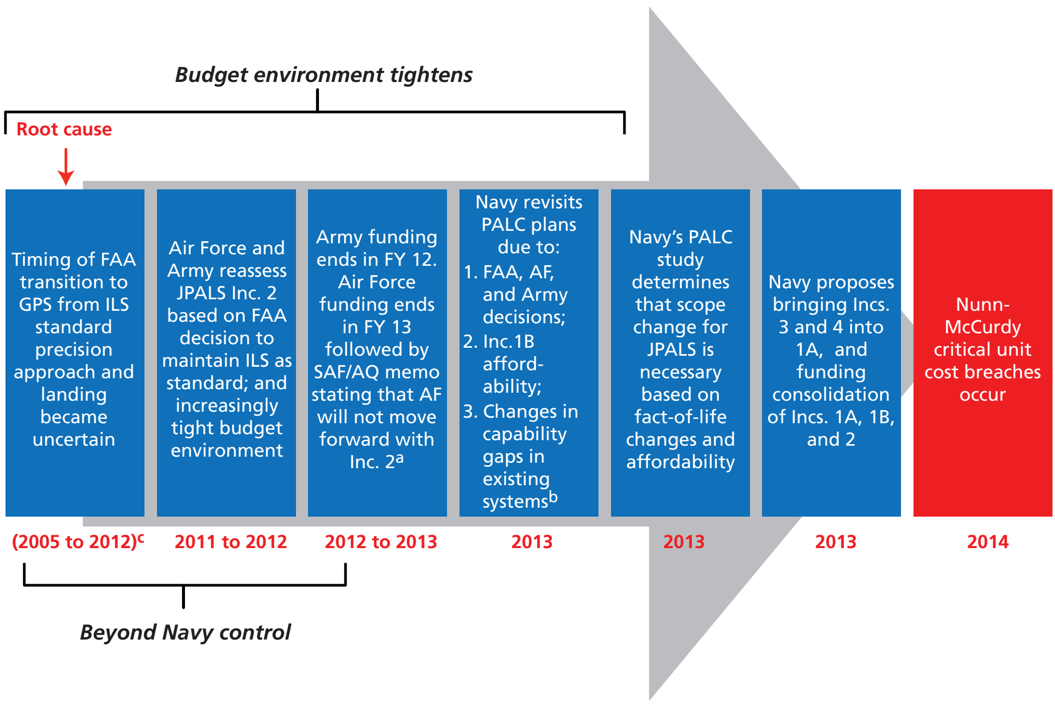


SOURCES: Department of Defense, JPALS Inc. 1 SARs, December 2009 through December 2013; Department of Defense, *Joint Precision Approach and Landing System Acquisition Strategy in Support of Milestone B for JPALS Increment 1A*, Washington, D.C., June 2008; Under Secretary of Defense (A&T), ADM, May 1996; Department of Defense, *Joint Precision Approach and Landing System Updated Analysis of Alternatives (AoA) Study Report*, November 17, 2005; Department of Defense, Department of Homeland Security, and Department of Transportation, *Federal Radionavigation Plans*, 2001, 2005, 2008, 2010, and 2012; Federal Aviation Administration, *Capital Investment Plan FY 13–17*, March 2012; Navy, Army, and Air Force budget documentation; multiple Air Force, Navy, and Army ADMs.

RAND *MG1171/8-5.1*

ing (and funding consolidation), which was motivated by the findings of the Navy's PALC Roadmap study, was initiated by a series of "fact-of-life" changes to the assumptions underpinning the original JPALS seven-increment plan. The most fundamental of these was the FAA's decision to continue with ILS indefinitely (thus setting off those fact-of-life changes in domino fashion). Figure 5.2 provides the series and timing of the events discussed above.

Figure 5.2
Root Cause of the JPALS Inc. 1A Nunn-McCurdy Breach



[a]According to a November 2012 Secretary of the Air Force for Acquisition (SAF/AQ) memo, because of recent affordability assessment, ongoing service life extension on legacy systems, and a change in operational need. The Army did not release an official memo, but zeroed out funding in April 2013 budget documents as did the Air Force. The Army has a standing unfunded requirement.
[b]A 2005 AoA identified gaps: operational interoperability with FAA, DoD, and international civil aviation organizations; supportability in all four operating environments; and an emerging gap in sea-based operations beginning in 2013 (CVN21, Joint Strike Fighter, Joint Unmanned Combat Air System).
[c]According to multiple FAA official planning documents (2001–2012), the phasedown of the standard precision and landing system, ILS, in favor of GPS-based precision approach and landing (PAL) technology did not begin as was planned in 2001. After 2008, the transition remained unclear.
RAND *MG1171/8-5.2*

Evidence Supporting Root Cause Analysis

A cornerstone of the JPALS implementation strategy was parallel development and implementation with the FAA LAAS, which was based on the same GPS GBAS technology. However, since the CDD was approved, the pace of the FAA LAAS implementation and phase-down of the legacy instrument landing system slowed.

As part of this analysis, we tracked the FAA decisionmaking regarding PALC from 2001 through 2012 in its official planning documents. We then focused on the three technologies most relevant to JPALS: ILS, WAAS, and LAAS. WAAS and LAAS both augment GPS-precision approach and landing using ground-based stations. WAAS is a satellite-based augmentation system. LAAS is a ground-based augmentation system. By

2012, LAAS had been wrapped into the GBAS category. Most important, we focused on the ILS decisions because ILS is the civil standard for precision approach and landing. The FAA was indecisive regarding the future of ILS because it changed the ILS drawdown multiple times. Table 5.2 provides information extracted from the Federal Radionavigation Plans over time for the three key FAA PALC technologies.

As explained above, the services had to make decisions regarding JPALS. The Army budget reflected the final funding for the Army's portion of the program in the Presidents' Budget, 2014.[1] The last funding provided in the budget was for FY 2012 at $8.297 million. There was no reported funding for FY 2013 (submitted in Febru-

Table 5.2
FAA Decisionmaking for Precision and Landing Capability

	2001 FRP)	2005 FRP	2008 FRP	2010 FRP	2012 FRP/ FY 2013–2017 Capital Investment Plan
ILS	ILS Cat I: Begin phasedown (2010); no phaseout planned for CatsII/III	ILS Cat I: Begin phasedown (2015); no phaseout planned for Cats II/III	ILS: No specific dates for phasedown provided in official 2008 plan	ILS: No specific dates for phasedown provided in official 2010 plan	ILS Cat I: Plans initial decision whether to begin drawdown (2014); plans to make decision in 2020 for decommission of remaining ILS
LAAS (ground-based GPS augmentation system)	LAAS Cats I/II/III: FOC (2011)	LAAS: Discussed as R&D with no designated milestones (2005)	LAAS Cat I: First system design approval (2008); LAAS Cat III: Design approval (2012)	LAAS Cat I: System design approval (Sept 2009); LAAS Cats II/III: FAA expects to make investment decision by 2012	GBAS Cat I: Can be implemented at airports; GBAS Cats II/III: Continuing R&D
WAAS) (satellite-based GPS augmentation system)	WAAS: IOC expected (2003); WAAS: primary means of navigation determination (2009)	WAAS: FAA Commissioned (July 2003)	WAAS: Achieved full-level performance build (2008)	WAAS: No additional relevant information provided	WAAS: Phases II and IV of the program

SOURCES: Department of Defense, Department of Homeland Security, and Department of Transportation, *Federal Radionavigation Plans*, 2001, 2005, 2008, 2010, 2012; Federal Aviation Administration, *Capital Investment Plan FYs2013–2017*, March 2012.

[1] Department of the Army, *Exhibit R-2: RDT&E Budget Item Justification: PB 2014 Army,* Washington, D.C., 0604201A: Aircraft Avionics, April 2013.

ary 2012) or FY 2014.[2] In addition, an article from *Jane's Defence Weekly* indicated that the Army would terminate JPALS.[3] According to one official associated with the program, the Army's reduced participation in JPALS was largely because of the sharp drops in the budget. The Army requirement for JPALS remains but is being carried as an unfunded requirement.

The Air Force budget said the following about the Air Force's transition out of the JPALS program in its April 2013 budget document:

> As reflected in the JPALS CDD, JPALS is intended to be the next generation precision approach and landing system which would provide a common interoperable system for both DoD and civil use. A cornerstone of the JPALS implementation strategy was parallel development and implementation with the Federal Aviation Administration Local Area Augmentation System (LAAS) which was based on the same GPS Ground Based Augmentation System (GBAS) technology. However, since the CDD was approved, the pace of the FAA LAAS implementation and phase down of the legacy instrument landing system has slowed. This, combined with an on-going tech refresh (life extension) of the legacy Instrument Landing System (ILS), development of a Deployable ILS, the fact that new platforms (F-35, KC-46) will be ILS equipped, and the need to fund higher Air Force priorities, the Air Force is delaying JPALS implementation for the foreseeable future. The Army has also delayed JPALS implementation beyond the current future years defense plan. As JPALS is now early to need for the Air Force, Land-Based Increment 2 development responsibility is being transferred from the Air Force to the Navy. Both Service Acquisition Executives are in agreement on transfer of the Land-Based Increment 2. The Navy has a near term need in FY17 for a shore based system to support Joint Strike Fighter carrier landing training. The Air Force will monitor the progress of JPALS implementation but, in the interim, continue the use of the legacy Instrument Landing System (ILS). ILS is supportable through the 2030 timeframe and, in its fixed and deployable configuration, will provide an effective and affordable landing system capability. The Air Force will also retain a limited number mobile precision approach radars to provide joint Service interoperability at deployed location as all Navy and Army aircraft are not ILS equipped. [4]

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2 According to the Army budget document, FY 2012 accomplishments included the following: Completed the Aircraft Integration Guide (AIG) effort related to the AH-64D platform, Block III. Completed nonrecurring engineering efforts for M-Code development. Completed Small Antenna System antijamming antenna cosite analysis and M-Code recurring prototyping. Completed the JPALS Common Avionics Technology Development (JCATD) effort, and continued to support JPALS Increments 1 and 2 development and program management coordination meetings, technical interchange meetings, and working groups.

3 Daniel Wasserbly, "U.S. Army Gives Details of the FY13 Budget Request," *Jane's Defence Weekly,* February 14, 2012.

4 Department of the Air Force, *Exhibit R-2: RDT&E Budget Item Justification: PB 2014 Air Force,* Washington, D.C., 0603860F Joint Precision Approach and Landing Systems—Dem/Val, April 2013.

As stated in this quotation, the Air Force mentioned that the JPALS Land-Based Increment 2 would be transferred to the Navy along with the Increment 2 development funding and that the Air Force would continue to use the ILS through the 2030 time frame. In addition, SAF/AQ provided a memorandum to the Assistant Secretary of the Navy for Research, Development, and Acquisition on November 29, 2012, stating: "Due to a recent affordability assessment; an ongoing service life extension on legacy landing systems and changes in operational needs, the United States Air Force (USAF) requirement for JPALS is deferred beyond the FYDP; however, the United States Navy (USN) need in the FY17 timeframe remains intact."[5]

Because of the decisionmaking environment of the FAA, the Army, and the Air Force along with DoD "budget constraints and affordability concerns," the Navy performed an internal analysis of the Navy PALC requirement.[6] The results were presented in June 2013.[7] In the January 2014 PDR, the Navy laid out more specifically a path moving forward that would lead to a restructured JPALS (see Figure 5.3):

> Under the recommended restructure, the JPALS Ship System (currently designated as Increment 1A) will continue to be developed and procured for use on US Navy aircraft carriers (CVN-type) and amphibious assault ships (LH-type) in support of the F-35B/C and Unmanned Carrier-Launched Surveillance and Strike (UCLASS) programs. JPALS will not be integrated into legacy CVN aircraft (prior JPALS Increment 1B aircraft integration), nor will JPALS be developed and procured for Navy and Marine Corps fixed based air stations or expeditionary airfields (prior JPALS Increment 2 land-based capability). JPALS will support manned and unmanned auto-land capability (prior JPALS Increments 3 and 4 auto-land and UAS support) and will be incorporated into the current single increment JPALS POR. Separate from the JPALS program, civil Instrument Landing System (ILS) capability will be procured and deployed at Navy and Marine Corps fixed-base air stations and integrated into legacy aircraft to address joint and civil interoperability gaps. Further, legacy shipboard landing systems will be recapitalized and/or sustained.[8]

The Navy also determined that it would eliminate the shore-based training systems, which reflects the reduction in quantity, and Milestone C would slip three years.

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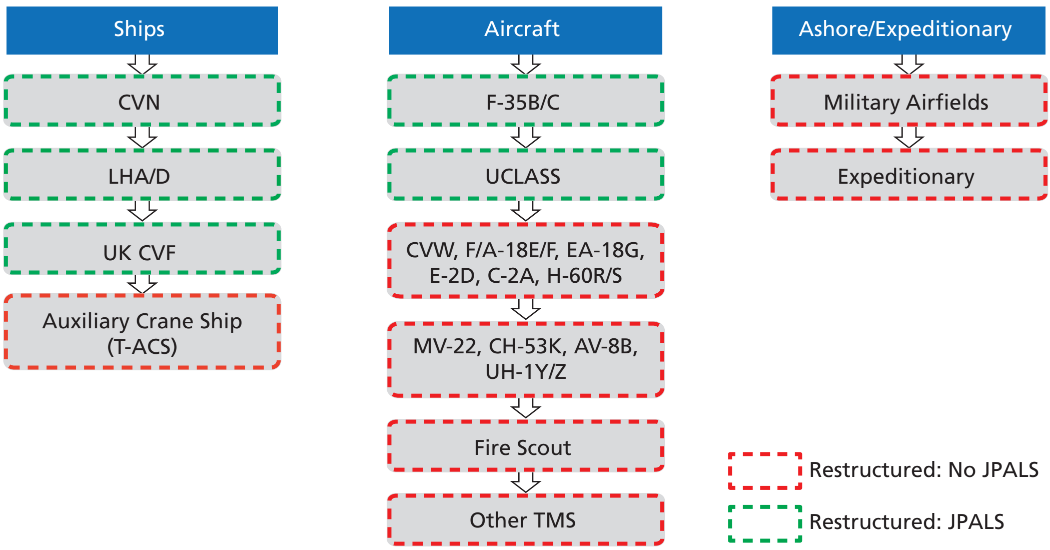
5 Lt Gen Charles R. Davis, U.S. Air Force, "Joint Precision Approach and Landing System (JPALS) Increment 2," memorandum for the Assistant Secretary of the Navy for Research, Development and Acquisition, November 29, 2012.

6 Lack, 2014, p. 1.

7 CAPT Brett K. Easler, *Department of Navy Precision Approach Landing Capability (PALC) Roadmap to Include Joint Precision Approach Landing System (JPALS) Re-Scope to Single Increment R3B Brief,* Washington, D.C., U.S. Navy, June 10, 2013. PRE-DECISIONAL/NOT FOR RELEASE.

8 Lack, 2014, pp. 1-2.

Figure 5.3
JPALS Restructure: Which Platforms Will Have JPALS?



SOURCE: Lack, 2014, pp. 1–2.
RAND *MG1171/8-5.3*

In this acquisition program, the Navy has always had a unique need for GPS-based precision approach and landing technology, and its decision to restructure JPALS was driven by a unique confluence of factors. This unique need arises mainly because various aircraft need to land on ships and carriers with landing platforms that are not stationary. The Navy has unique precision landing requirements where landing is inherently more risky than it is on land, and those requirements could not be fulfilled by means other than JPALS:

- sea-based operations (e.g., landing on carrier)
- F-35B/C design risk/dependency
- improved precision landing system required for UCLASS, which is an aircraft with no pilot.

Also, updating legacy Navy systems is more affordable than transitioning all legacy systems to JPALS:

- ILS incorporation onto legacy aircraft (e.g., F/A-18); solves interoperability problem within DoD and FAA.
- SPN-46[9] restored on CVN 78 and CVN 79.

[9] AN/SPN-46, or ACLS, is the carrier's only fully automated, all-weather approach landing aid for carrier aircraft.

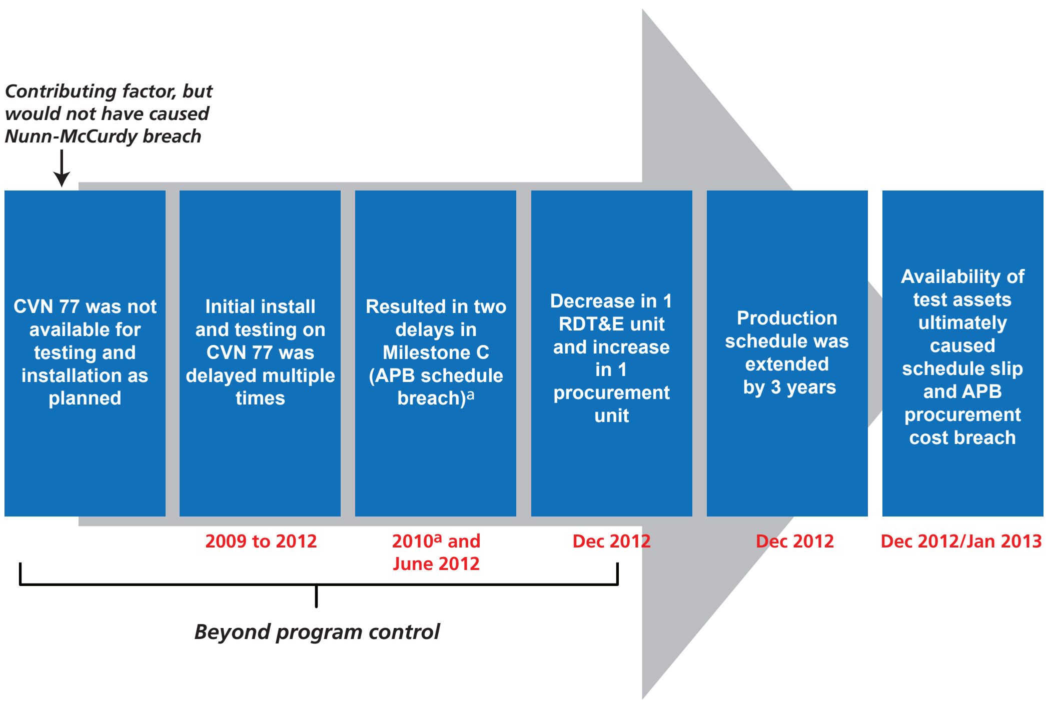
- Supportability gaps in legacy systems have been addressed.
- Potential for greatly improved UAV capabilities in the longer run.

Contributing Factor: Program Interdependencies Caused Cost Growth and Schedule Slip in Increment 1A

The baseline program—Inc. 1A—incurred some modest cost and schedule growth, independent of the factors affecting the Navy's decision to restructure the program. Figure 5.4 provides the series of events that resulted in cost growth in the Inc. 1A program.

The JPALS Inc. 1A program of record required shipboard Integrated Testing and Operational Assessment. The testing was planned to occur on the CVN-77. According to the PDR from July 2012, several shifts from 2009 to 2012 to CVN-77 installation availability occurred, resulting in a delay in operational assessment (OA) testing and,

Figure 5.4
The Effect of Program Interdependencies



SOURCE: Lack, 2012a.

[a]In 2010, the Milestone C date changed from February 2013 to May 2013. In April 2012, Milestone C was changed from May 2013 to November 2013 resulting in an APB schedule breach.

RAND *MG1171/8-5.4*

consequently, a slip in Milestone C from May 2013 to November 2013, which was an APB schedule breach.[10] This shift also resulted in a decrease of one RDT&E unit and an increase of one unit to procurement. The new procurement quantity needed to satisfy a new production schedule, which was extended by three years. Consequently, some fixed cost increases are directly attributable to the new production schedule to include additional government and contractor staffing and extending the production contract by three years. The increase to procurement units and fixed costs caused an APB procurement cost breach.[11]

A detailed review of SAR change explanations and DAES assessments suggests that three basic factors account for approximately 10 percent of the Inc. 1A program cost growth:

1. underestimation of required government and contractor system engineering, system integration, and program management personnel and activities
2. test asset availability
3. procurement and installation schedule slip.

The underestimation of system engineering manpower and activities largely reflects the challenge of developing the algorithm that constitutes the core capability of JPALS. Test asset availability and the schedule slip to accommodate a revised production profile and installation schedule are direct effects of program interdependency. The slip in schedule eventually caused an APB schedule breach to Milestone C and an APB procurement cost breach.

Findings

Root causes are an input to understanding changes in program costs. We linked the root causes back to the cost drivers as seen in program documentation and in the SARs. We used the rubric and color coding in Figure 5.5, to help highlight where root causes are linked to technical factors that affected cost drivers. For instance, the FAA decisions led to a restructuring of the requirements, which led to increased scope in the current SAR. The other cost drivers we identified include reduction in quantity, contract cost growth, and stretched schedule.

Once we selected the most appropriate connections between the root causes and the cost drivers, data on cost drivers from each of the annual SARs were aggregated, coded to the categories shown in Figure 5.5, and analyzed to understand cost

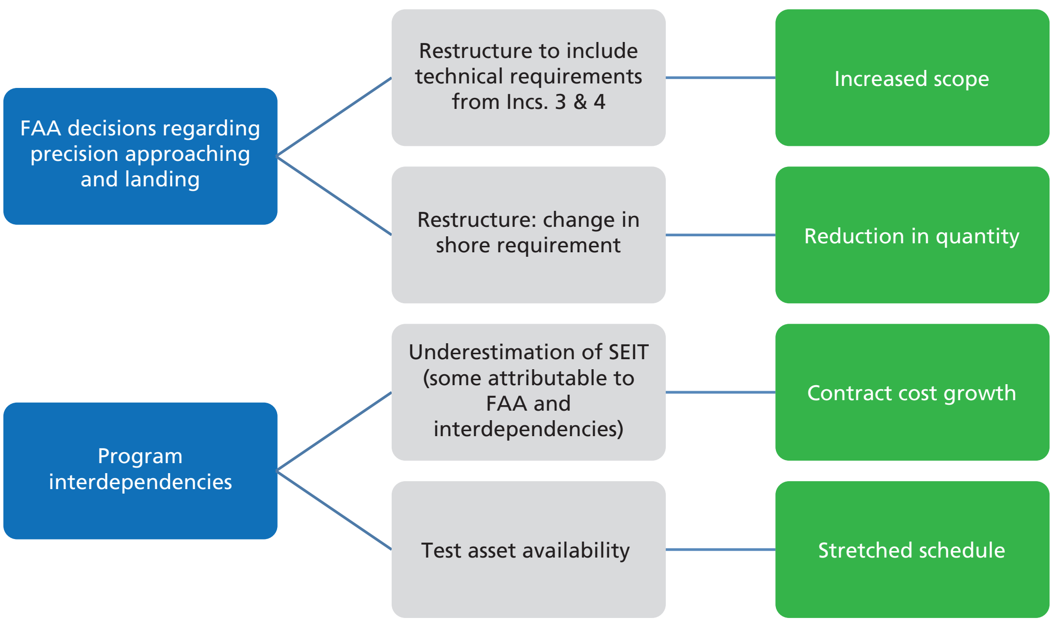
[10] An APB schedule breach is slippage of six months or more from the target baseline.

[11] Lack, 2012a. An APB procurement cost breach occurs when cumulative program cost increases greater than or equal to 10 percent.

growth in RDT&E and procurement. In the SARs, there are occasional downward cost adjustments, which are not directly connected to the root causes but are captured in the analysis process. In this report, we summarize the net effect of these changes in the following figures. Figure 5.6 shows that there was almost $50 million in downward adjustments in the SARs, which includes estimating (adjustment for current and prior escalation; budget cuts from DoD and Congress). An additional $71.6 million was associated with underestimating systems engineering, integration, and testing (SEIT) in the Inc. 1A program and therefore contract cost growth. This $71.6 million was directly related to meeting the original requirements outlined in JPALS Increment 1A. RDT&E grew an additional $334.6 million because of the restructuring of the program leading to increased scope from Increments 3 and 4. Increments 3 and 4 were not fully defined, so the incorporation of these dollar values into Increment 1A introduces new uncertainty. For instance, the period of development has been extended in the restructure at a cost of $215 million. New requirements associated with automatic landing capabilities increased the RDT&E costs approximately $120 million more.

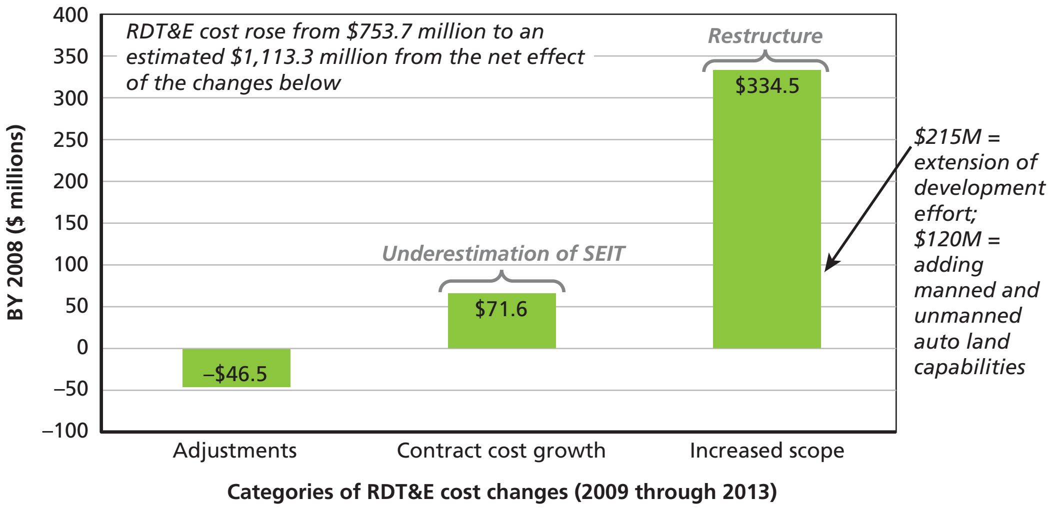
For procurement, the cost adjustments in the SARs reveal a similar pattern with a few costs attributable to the original scope of JPALS Inc. 1A but the majority of

Figure 5.5
Drilling Down from Root Causes to Cost Drivers



SOURCE: RAND analysis.
NOTES: Blue is a root cause. Gray is technical factor or other change in the program based on a root cause. Green is the consequence.
RAND *MG1171/8-5.5*

Figure 5.6
Program Restructure Drove RDT&E Cost Increase, 2009 Through 2013



SOURCES: RAND analysis; Department of Defense, JPALS Inc. 1A SARs, December 2009 through 2013.
RAND *MG1171/8-5.6*

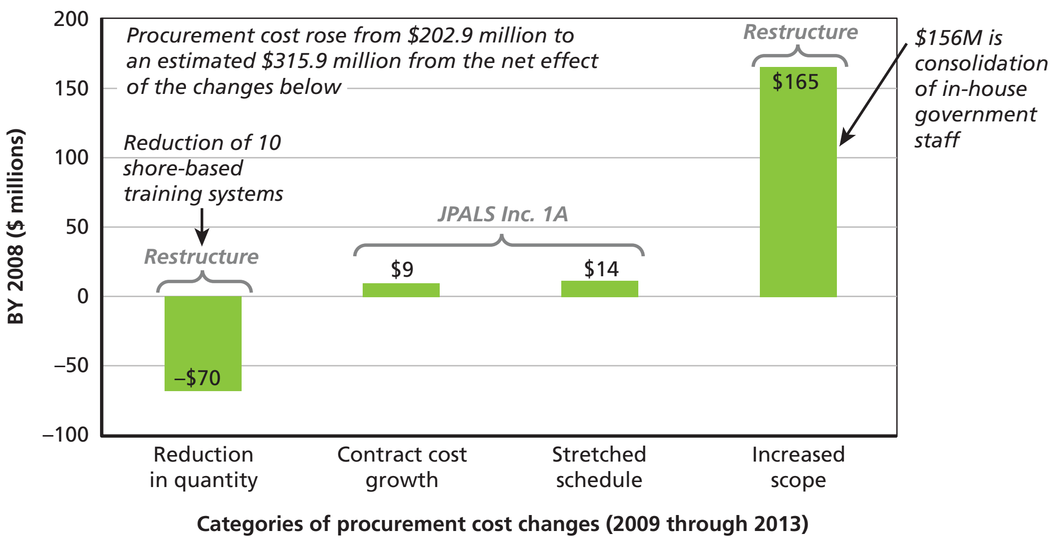
changes associated with restructuring the program as exhibited in Figure 5.7. Contract cost growth and stretched schedule added about $19 million. Procurement decreased by $70 million because of the reduction in shore infrastructure by a quantity of 10. Increasing the scope of the current JPALS program of record added an additional $165 million because of shifting government staff from later increments and other small restructuring costs.

Once all of the cost variances from the SARs are categorized, it is possible to summarize the cost driver effect at the unit cost level and associate each with a percentage. This gives us a better understanding of the increase in costs based on spreading those costs over fewer units. The first step is to identify the baseline cost of interest from the SAR, either the PAUC or APUC. Figure 5.8 includes PAUC and, therefore, for this calculation we used the total program cost and the cost variances for RDT&E and procurement combined. Then we took the total cost and subtracted the cost variance of interest (contract cost growth, stretch schedule, increased scope, etc.). Then this number is divided by the new quantity. Finally, we take this number and subtract the baseline PAUC to see the increase in costs based on spreading cost increases over fewer units.

These calculations reinforce the notion that stretched schedule and contract cost growth are minor drivers of JPALS cost growth and that the reduction in quantity and increased scope have accounted for over 85 percent of cost growth.

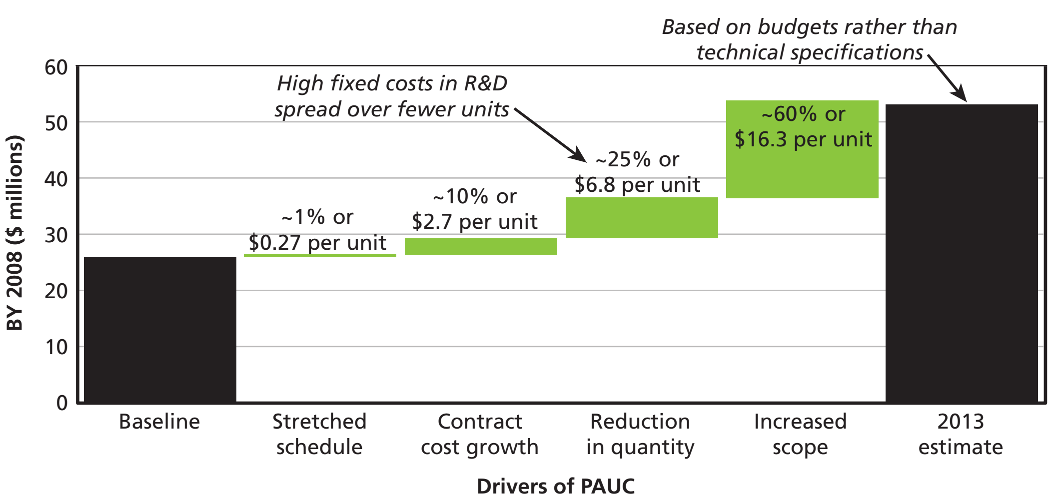
The next unit cost driver calculation is similar to the prior one but is limited to procurement costs because its baseline is APUC. First, we identified the total cost

Figure 5.7
Increased Scope from Incs. 3 and 4 Drove Procurement Cost Increases, 2009 Through 2013



SOURCES: RAND analysis; Department of Defense, JPALS Inc. 1A SARs, December 2009 through 2013.
RAND *MG1171/8-5.7*

Figure 5.8
Scope Change Is the Major Driver, But Lower Quantity Means That RDT&E Is Spread over Fewer Units in the PAUC Metric



SOURCES: RAND analysis; Department of Defense, JPALS Inc. 1A SARs, December 2009 through 2013.
NOTE: Numbers may not add to 100 percent because of rounding.
RAND *MG1171/8-5.8*

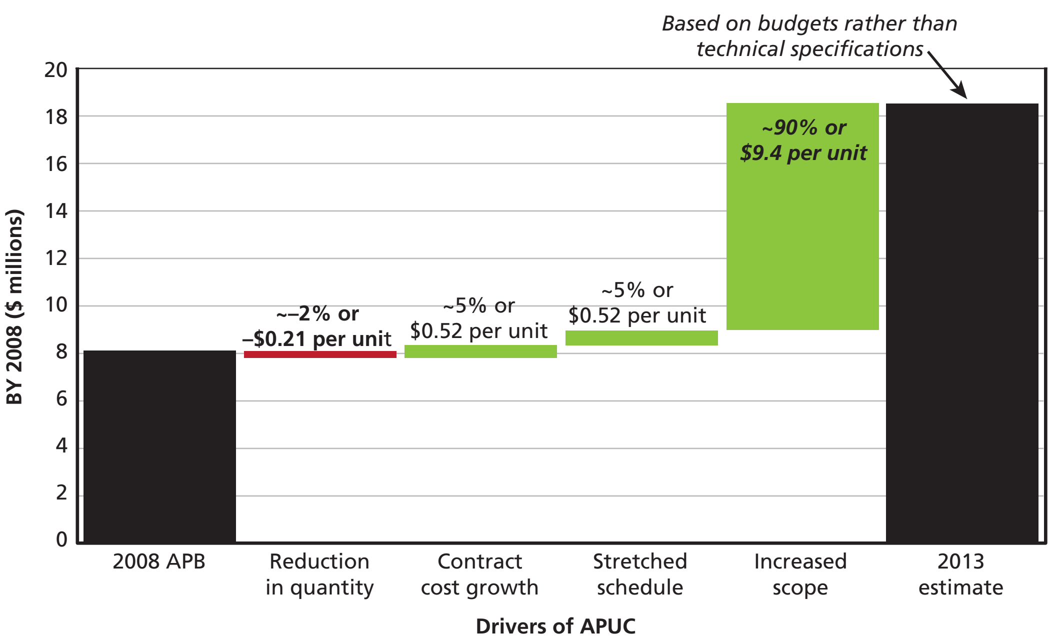
associated with procurement and the cost variances associated with procurement dollars. Then, we took the total cost and subtracted the cost variance of interest. Next, we divided this number by the new quantity, and, finally, we subtracted the baseline APUC. The resulting number is the effect of that cost variance on the procurement unit cost. As shown in Figure 5.9, it appears from the data that the shore-based facilities that were eliminated during the restructuring may have cost more per unit than the ship-based counterpart. Therefore the cost associated with reducing the quantity in this case is unusually negative. Of course, the smaller quantity did mean that other cost variances had a great influence on unit cost.

For the APUC, contract cost growth and stretched schedule have a minimal effect on unit cost growth. Increased scope shifted new dollars from other increments and therefore accounts for 90 percent of the unit cost growth.

Limitations

After our initial analysis, PARCA used these findings along with the unpublished cost estimates developed by cost analysts at the office of Cost Assessment and Program Eval-

Figure 5.9
About 90 percent of APUC Growth Was Driven by Increased Scope



SOURCES: RAND analysis; Department of Defense, JPALS Inc. 1A SARs, December 2009 through 2013.
NOTE: Numbers may not add to 100 percent because of rounding.
RAND *MG1171/8-5.9*

uation (CAPE) to develop the official root cause analysis memo.[12] These new CAPE cost estimates gathered new information from the program and the contractors beyond what was available at the time of SAR publication. This additional estimate allowed PARCA to refine the percentage of cost growth related to each driver with information beyond what was available in the SAR. Therefore, the final cost growth percentages in the memo deviate slightly from our characterization here, but the direction and magnitude of cost growth attributed to the root causes are similar to those in our findings.

[12] Gary R. Bliss, "Root Cause Analysis of the Joint Precision Approach and Landing System increment 1A (JPALS Inc 1A) Program," memorandum for the Under Secretary of Defense (AT&L), Washington D.C., May 23, 2014.

CHAPTER SIX

Conclusions

The JPALS program is a joint acquisition effort based on an important assumption that the FAA and DoD would collectively transition to a GPS-based precision approach and landing capability, which proved to be false. Between 2005 and 2012, the timing of the FAA decision to transition to GPS from the ILS standard for PALC became uncertain. As a result, the Air Force and Army reassessed JPALS Inc. 2 because of the FAA decision to maintain ILS as standard and an increasingly tight budget environment. Army funding for JPALS ended in FY 2012, and Air Force funding ended in FY 2013 followed by a SAF/AQ memo stating that the Air Force would not move forward with JPALS Inc. 2. Taking into account the decisions by the FAA, the Army, and the Air Force, the Navy revisited its PALC plans. The PALC assessment concluded that Inc. 1B was unaffordable for the Navy and that, over time, there would be changes in capability gaps in existing systems. The Navy's PALC study also determined that a scope change for JPALS was necessary because of fact-of-life changes and affordability. The Navy proposed bringing Incs 3 and 4 into 1A and consolidating funding for Incs 1A, 1B, and 2. More specifically, the reduction in total planned quantities in the Inc. 1A program because of the elimination of previously required shore-based training systems, an extension of the development program to include capability improvements, a lower and longer procurement profile, and increases in material costs resulted in a critical Nunn-McCurdy unit cost breach to the PAUC and APUC in the current JPALS Inc. 1A program.

The cost drivers for the critical unit cost breaches of both the PAUC and APUC against both baselines in order of importance are as follows:

- increased program scope/requirements change
- engineering and manufacturing development (EMD) extension to incorporate Incs. 3 and 4 into Inc. 1A
- consolidated funding for staff and extended coverage under a restructured single increment program
- quantity reduction spreading nonrecurring costs over fewer units
- schedule stretch for Inc. 1A and flatter production profile

- underestimation of the SEIT effort because the algorithms were more difficult than anticipated.

The JPALS Inc. 1A program also experienced SEIT asset availability challenges (particularly with the CVN testing) that resulted in cost growth of approximately 10 percent including:

- movement of one RDT&E unit to procurement
- APB schedule and procurement cost breaches
- some unit cost growth.

However, the 10 percent growth in the JPALS Inc. 1A program would not have caused any Nunn-McCurdy breaches.

After recertification of a program with a critical Nunn-McCurdy breach, PARCA is responsible for continued monitoring of the program's performance to provide situational awareness of future execution issues and guard against repeat Nunn-McCurdy breaches. During the course of our root cause analysis, we identified a set of risks with the potential to cause a future breach. This set is not intended to be a comprehensive list of future risks for the restructured JPALS program, and we do not attempt to assess the relative importance or consequences of these risks. Rather, we offer this discussion of potential future risk as a starting point for PARCA's continued monitoring on the program.

The development risk associated with the incorporation of previously defined Incs. 3 and 4 capabilities into the restructured JPALS program is one future risk. We did not examine the capabilities and technologies involved specifically, but developing increased capabilities—capabilities that increase or add to performance of the baseline system—generally presents some degree of technical or programmatic risk. The risk may manifest as poor or incomplete requirements definition and translation into performance specifications, unanticipated software development or system integration challenges, or even future budget reductions or reduction in demand for the future capability.

A related risk is that, at the time of this writing, the technical baseline for what was Inc. 4 capability had not been sufficiently defined. This capability is intended to enable precision landing of UAVs and is part of the restructured JPALS program. A poorly or incompletely defined technical baseline introduces significant risk into the cost and schedule estimates that will be baselined at Milestone B after program recertification.

The requirement for the capabilities that the restructured JPALS program produces appears to be limited to the F-35B/C and UCLASS (or other future sea-based UAVs). Slips in the F-35 B/C program could adversely affect JPALS cost and schedule. Similarly, the UCLASS program has not been fully defined, and its demand for JPALS

has not been formalized into an approved requirement. Changes in the deployment timing or quantities could lead to changes in the JPALS program. This is really just a continuation of the program interdependencies factor discussed above.

As noted above, performance of the JPALS Inc. 1A capability has largely been demonstrated using JPALS EDMs and representative aircraft integration kits installed on C-12 or F/A-18 aircraft. Recent testing has also begun to demonstrate some of the Inc. 3 capabilities that will become part of the restructured program. Because the operational need for JPALS is linked to the deployment of the F-35B/C and UCLASS, and those aircraft are not expected to become operational for several years, the restructured JPALS program includes a production gap based on the restructured JPALS program's new Milestone C and low-rate initial production (LRIP) dates. This suggests a possible loss of learning affecting manufacturing and integration of the JPALS system, as well as the risk of hardware obsolescence. Either of these risks associated with the extended scheduled of the restructured JPALS program could affect program cost in the future.

Part Two

Assessing the Department of Defense Weapons System Acquisition Portfolio

CHAPTER SEVEN

A Methodology for Assessing the Department of Defense Acquisition Portfolio

Developing an Approach to Portfolio Assessment

For the purposes of oversight and monitoring, planning and programming, and decisionmaking regarding development and procurement, policymakers and leaders of the defense acquisition community need to be able to describe and assess the status and performance of portfolios of MDAPs over time. For example, they may need to evaluate the maturity, average unit cost growth, amount of churn (or number of programs with a quantity change), or trends in funds remaining of a specific category or group of programs (e.g., helicopters, satellite, ships, fighter jets, and others) and be able to summarize the performance of these programs using a clear and easy to understand set of metrics and visualizations. They may also be interested in how this portfolio's performance changes over time, how its performance compares to other portfolios, and even how the composition of the portfolio itself may be evolving (e.g., which programs have been completed or cancelled, and which are still ongoing).

This chapter presents a methodology and set of metrics that can be used to characterize the status and risk of portfolios and subportfolios of MDAPs over time and across commodity types. It responds to an interest expressed by PARCA in developing a clear and repeatable way to assess and summarize the overall performance of a set of acquisition programs at a given point in time and over a longer time span. The primary audience for this part of the report consists of analysts in the acquisition community who might use the metrics and visualizations to understand the performance of many portfolios across several different dimensions. The assessments and insights derived from these visualizations may also be of use to policymakers. However, it is worth noting that the methodology itself is the most significant contribution of our discussion of portfolio assessment and metrics.

To begin, it is necessary to define what is meant by the term *portfolio* in the context of this chapter. We use the term portfolio to refer to a set of acquisition programs that can be grouped together because they share a certain characteristic or several characteristics. For example, the helicopter portfolio is a set of all helicopter programs. Portfolios can be designed and constructed in any number of ways depending on the

interests of analysts. For instance, portfolios might be based on Defense Acquisition Management Information Retrieval (DAMIR) program types (all force application or logistics programs, for example). Or, they might be based on the agency or service that owns the program. These portfolios would include all Army, all Navy, or all DoD programs. Another type of portfolio might be constructed around individual contractors, with each portfolio including all the programs currently managed by key DoD contractors. Finally, a portfolio might be organized to include all programs at certain points in the program life cycle, past Milestone C or approaching Milestone B, for example. We refer also in the report to *subportfolios*. Subportfolios include smaller sets of MDAPs with similar characteristics. The analysis of a subportfolio allows us to study the status of these smaller sets of programs in more detail and to separate their status from the status of the overall portfolio of MDAPs and the status of other subportfolios.

There is no set methodology for constructing a portfolio of programs. Instead, the construction will be based on the interests and priorities of policymakers and analysts. For example, analysts interested in understanding the overall performance of all programs owned by each service will want to construct larger portfolios based around each individual service. In contrast, an analyst interested in understanding the performance of individual program types within the Army's larger portfolio of programs might construct and analyze subportfolios of programs including aircraft, wheeled vehicles, and weapons. Portfolios may even be formed around sets of programs that are more different than alike. For example, "all programs experiencing a cost breach in past five years" would be a possible portfolio of programs, and the resulting portfolio would contain significant diversity. However, ultimately, the analysis of this portfolio would be useful in assessing the overall performance and continued risk of this set of programs. Thus, the construction of a portfolio is a flexible concept that can be molded to address the specific questions asked by an analyst or policymaker. This flexibility increases the utility of portfolio-level analysis for the acquisition community.

There are no size requirements when defining and constructing portfolios of programs. Instead, what is most important is that all programs in a given portfolio share key characteristics and are included in the portfolio for specific reasons. A portfolio of programs could contain hundreds of programs or only a few. Different methodologies for assessing portfolio performance might be used for different size portfolios. The methodology described in this report will likely be most useful when the number of programs is relatively small—probably less than 25 programs (but more than five or so). This is because the set of metrics included are relatively extensive, and some of the visualizations are complicated to create when the number of programs becomes too large. Also, when portfolios are too large, it may be difficult to drill down and explain the drivers of key portfolio-level trends. As will become clear in our sample portfolios, whereas the first step of portfolio analysis requires looking at summary trends, the second step involves digging deeper and understanding the drivers of those trends. This is harder to do when there are so many different programs. However, when there are

too few programs, the portfolio view is also less useful, because it will be similar to a program-level analysis of any individual program and is likely to be easily influenced by individual programs within the portfolio.

There are several advantages to studying acquisition program performance at the portfolio level. A summary analysis can provide a broader insight into the performance of a set of acquisition programs—current status, future risks, and overall performance trend. As a result, it gives a more accurate picture of overall acquisition performance than focusing on individual programs, be they strong performers or programs with significant problems and challenges. The portfolio-level analysis can also identify programs and portfolios that are at risk, that need additional investment, or that are performing particularly well. Although it is difficult to compare performance across some portfolios given their extensive differences (comparing helicopters to wheeled vehicles, for example), comparisons across other types of portfolios might be more meaningful (for example, comparing Army programs to Navy programs). This type of comparison might help acquisition analysts identify broader families or types of programs that are more or less at risk for performance problems or that have contributed more or less to such problems as cost growth and slippage in the past. A portfolio-level assessment can also help acquisition analysts understand the ways in which a given portfolio may be at risk. For example, a portfolio that has high and increasing cost growth may pose a different kind of risk than one with low cost growth but faster than expected RDT&E or procurement spending. Being able to diagnose which portfolios are performing well and which pose more risk (and what type of risk they pose) can help acquisition analysts manage the overall risk incurred by DoD and plan for future acquisitions.

For the reasons noted above, analysis of acquisition performance conducted at the portfolio level may be useful. To facilitate this type of analysis, we have focused in this report on the development of a methodology and a set of metrics that can be used to conduct portfolio analysis. Our focus throughout the report is on defining and discussing metrics and visualizations of these metrics that can be used as part of a valuable portfolio assessment. We discuss the types of data sources that can be used, challenges associated with these data sources, and ways to overcome these challenges. We also provide clear rationale for why we have chosen the metrics that we have included and suggest a range of different metrics and visualizations that may be useful to analysts with varied interests and objectives. We then use two example portfolios to demonstrate and refine our chosen methodology: the satellite and helicopter portfolios, from 2002 to 2012. Our example portfolios allow us to validate and demonstrate our methodology and to provide and interpret data visualizations that a policymaker could use to understand and describe the status of various portfolios and subportfolios. We use one of these portfolios, the helicopter portfolio, to conduct a more in-depth assessment, demonstrating how our methodology and metrics can be applied and inter-

preted to provide an expanded assessment of portfolio status and performance.[1] However, throughout the chapter our focus remains the definition of a methodology and selection and discussion of the metrics and visualizations included in this methodology. We do not provide a comprehensive portfolio assessment but rather offer analysts an approach and a set of tools and visualizations that they can use to do so.

It is worth noting that other methodologies could be and already are used to assess program and portfolio performance. For example, the "Probability of Success" Method used by each service is one approach to evaluating the performance and risk inherent in a given portfolio of programs.[2] That model evaluates programs on five dimensions requirements, resources, program execution, fit in the vision, and advocacy. The metrics can also be used to assess the "probability of success" for individual programs. As with the portfolio assessment methodology presented in this report, the probability of success model considers many aspects of program performance (beyond cost, schedule, and performance) and uses graphical presentations to summarize performance trends. However, the focus of the methodology presented in this report is not to assess the performance of individual programs but to provide aggregate, portfolio-level views that provide a summary of the status of an entire portfolio and trends over time.

Organization of Part Two

Chapter Eight documents our methodology for constructing a portfolio analysis, including defining objectives, selecting a portfolio, vetting data and metrics, and visualizing the results. To illustrate this methodology, we include examples from two different portfolios we examined in more depth: the helicopter and satellite programs from 2002 to 2012. Most important, the methodological approach we used built on existing related work on anticipating breaches that had already reviewed a large number of metrics and performed data collection and processing on a set of acquisition programs.[3] Chapter Nine presents a final outcome for our own constructed portfolio analysis of helicopter and satellite programs, which includes the set of visualizations that indicate status, trends, and patterns with the portfolio metrics. We focus in this chapter on our methodology, metrics, and visualizations rather than giving a complete assessment of the programs in the portfolios that we consider. Chapter Ten provides an example

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[1] In Appendix B, we provide information on an initial "test case" portfolio that we used in developing the methodology.

[2] For more on the Probability of Success Method, see John Higbee and LTC Robert Ordonio, "Program Success: A Different Way to Assess It," *AT&L Magazine,* May 2005.

[3] Mark V. Arena, John Birkler, Irv Blickstein, Charles Nemfakos, Abby Doll, Jeffrey A. Drezner, Gordon T. Lee, Megan McKernan, Brian McInnis, Carter C. Price, Jerry M. Sollinger, and Erin York, *Management Perspectives Pertaining to Root Cause Analyses of Nunn-McCurdy Breaches, Volume 6: Contractor Motivations and Anticipating Breaches*, Santa Monica, Calif.: RAND Corporation, MG-1171/6-OSD, 2014.

followup narrative that may result from additional questions from a policymaker inspired by the results of the initial portfolio assessment. In the concluding chapter (Chapter Eleven), we describe the limitations and next steps in the research, including performing a more complete portfolio assessment.

CHAPTER EIGHT

Construction of a Portfolio Analysis: Objectives, Portfolios, Data, Metrics, and Visualization Selection

In this chapter, we present a general framework to construct a portfolio analysis that provides flexibility to incorporate policymakers' priorities and assumptions. As a means of demonstration, we provide examples of three portfolio frameworks we examined as we worked to fine-tune and develop this method. After identifying analysis objectives and assumptions, we discuss the selection of portfolios and data sources, providing information about the selection of metrics at the program and portfolio levels. We also discuss possibilities for data packaging and visualization techniques that we used in our analysis. The following chapters then expand on our assessment of our example portfolios. Because the goal of the initial phase of this work was to develop a methodology that can be used to assess portfolio status, we spent a considerable effort on this first step of the framework construction to document our rationale for each methodological step and decision in this chapter of the report.

Identifying Portfolio Analysis Objectives

Before beginning a portfolio analysis, it is important to outline the objectives of the analyst or, more important, of the policymaker in taking a portfolio view as opposed to an individual program view. These objectives may range from the priorities of an individual policymaker to tracking the success of DoD-wide acquisition policies. For example, by taking the portfolio view, one may assess the portfolio-wide implementation and results of implemented policy, such as Better Buying Power 2.0.[1] From these identified objectives flow a set of assumptions as to how one rates the "performance" of a chosen portfolio. Again, to build from the Better Buying Power 2.0 example, acquisition officials have adopted "affordability constraints" to track individual programs,

[1] Initiated in 2012 by Frank Kendall, Under Secretary of Defense for Acquisition, Technology and Logistics. The initial version of Better Buying Power 3.0 was released in September 2014. See Frank Kendall, Under Secretary of Defense Acquisition, Technology and Logistics, "Better Buying Power 3.0: White Paper," September 19, 2014.

such as affordability unit cost and operations and sustainment (O&S) goals and cap metrics, which allow for the grading of program performance in these areas.[2] These predefined metrics (for example, if unit cost rises above a certain value, this signals bad performance) help perform quick assessments on programs and, in the aggregate, the acquisition portfolio. Although outlining metric assumptions derived from the portfolio analysis's objectives help to scope the analysis, one must always use the objective itself as a frame of reference, as patterns or trends within the data may point to negative or positive implications not covered by predefined assumptions. Within our own example portfolios, our main objectives were to identify cost and schedule risk indicators.

Objectives for the portfolio analysis will be heavily influenced by the choice of the portfolio itself. For the purposes of this report, we define a portfolio as a group of acquisition programs sharing a defined set of characteristics. The possibilities for portfolio selection within defense acquisitions are numerous. Several examples for defined portfolio "types" include acquisition type (MDAP, Major Acquisition Information System [MAIS], etc.), service, commodity type, size (in dollars), contractor, contract type, time frame, or other characteristics that may be of interest to a policymaker. If they share the same "type," multiple, analogous portfolios may then be compared, such as the Air Force acquisition portfolio versus the Navy acquisition portfolio.

After developing and refining our methodology using a test case portfolio of MDAP programs (see Appendix B), we applied the methodology to two commodity-specific portfolios over a period of 11 years, starting in 2002 and ending in 2012. The component types were based on DAMIR pre-defined "Type" portfolios, and the two we selected were the helicopter programs and satellite programs. These portfolios contained all active MDAPs reporting SAR data at any time between December 1, 2002, and December 31, 2012.

Part of our motivation for selecting the satellite portfolio is recent interest by the sponsor and the acquisition community in evaluating risk in satellite programs.[3] The satellite portfolio included a total of 12 programs between 2002 and 2012. At any given time during that period, between seven and nine programs were active and reporting SAR data. A majority of the programs in this portfolio were Air Force pro-

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2 Obtained from the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, "Affordability Constraints of ACAT-ID IAM Programs for Components 9-15-14.xlsx," DAMIR Files, undated.

3 Risks and cost growth of satellite programs have been addressed by a number of recent publications, including Myron Hura, *Space Capabilities Development: Continued Difficulties and Suggested Actions*, Santa Monica, Calif.: RAND Corporation, 2011, Not available to the general public; Obaid Younossi, Mark A. Lorell, Kevin Brancato, Cynthia R. Cook, Mel Eisman, Bernard Fox, John C. Graser, Yool Kim, Robert S. Leonard, Shari Lawrence Pfleeger, and Jerry M. Sollinger, *Improving the Cost Estimation of Space Systems: Past Lessons and Future Recommendations*, Santa Monica, Calif.: RAND Corporation, MG-690-AF, 2008; Government Accountability Office, "Space Acquisitions: DOD Faces Challenges in Fully Realizing Benefits of Satellite Acquisition Improvements," Washington, D.C., GAO-12-563T, 2012; Ellen Pawlikowski, "Space Acquisition Issues in 2013," *Air & Space Power Journal*, September–October 2013.

grams. Table 8.1 shows all the programs that made up the satellite portfolio by year, service, and latest milestone achieved by year.

Because the satellite portfolio includes mainly Air Force programs, one reason for choosing the helicopter portfolio was to also include programs under the Army's control and a more representative sample of programs under the Navy's control. The helicopter portfolio included 13 programs between 2002 and 2012 with between seven and 10 programs active and reporting SAR data at any given time. A full list of the programs in the helicopter portfolio by year, service, and by the last milestone achieved by year is outlined in Table 8.2.

Selecting Data and Metrics

The identified objectives for the portfolio analysis should frame the selection of data metrics to perform the assessment. An analyst must also consider the ease of access to the data as well as the amount of labor required to gather and clean the data for the

Table 8.1
Satellite Portfolio Composition Between 2002 and 2012

Program	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
						Air Force					
AEHF	B	B	B	B	B	B	B	B	B	B	B
GBS	B	B	B	B	B	B	B	B	B	B	B
GPS III							B	B	B	C	C
GPS OCX											B
NAVSTAR GPS	B	B	B	B	B	B	B	B	B	B	B
NPOESS	C	C	C	C	C	C	C	C	C	C	
SBIRS-High	B	B	B	B	B	B	B	B	B	B	B
SBSS						B	B	B	B		
TSAT			B								
WGS	B	B	B	B	B	B	B	B	B	B	B
						Navy					
MUOS			B	B	C	C	C	C	C	C	C
NESP	C	C	C								

NOTES: A red B indicates that the program has passed Milestone B, and a blue C indicates that the program has passed Milestone C. A blank cell in the table suggests that the program has not started reporting SAR data, has been cancelled, or is no longer required to report SAR data.

Table 8.2
Helicopter Portfolio Composition Between 2002 and 2012

Program	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
					Army						
ARH				B	B	B	B				
CH-47F	B	B	C	C	C	C	C	C	C	C	C
Comanche	B	B									
UH-60M	B	B	B	C	C	C	C	C	C	C	C
AH-64D Longbow Apache[a]	C	C	C	C	C	C	C	C	C		
LUH					C	C	C	C	C	C	C
AH-64E Remanufacture[a]					B	B	B	B	C	C	C
AH-64E New Build[a]									C	C	C
CH-53K				B	B	B	B	B	B	B	B
					Navy						
H-1 Upgrades	B	B	B	B	B	B	C	C	C	C	C
MH-60R	B	B	B	B	C	C	C	C	C	C	C
MH-60S	C	C	C	C	C	C	C	C	C	C	C
VH-71				B	B	B	B				

NOTES: A red B indicates that the program has passed Milestone B, and a blue C indicates that the program has passed Milestone C. A blank cell in the table suggests that the program has not started reporting SAR data, has been cancelled, or is no longer required to report SAR data. Our team chose these three portfolios both to test our methodology and present examples for future analysts to follow in their own portfolio analyses. Again, one may choose from a variety of acquisition characteristics to create a portfolio or a set of analogous portfolios for comparison.

[a] Three separate Apache acquisition programs are covered in this analysis. The AH-64D Longbow Apache was reported in the SARs from 1997 through 2010. It is referred to as "Longbow Apache" in subsequent figures in this analysis. The AH-64E Remanufacture started its SAR reporting in September 2006 under the name of "Longbow Apache–Block III (AB3)." It then was reported under the following names: Apache Block III (AB3), Apache Block IIIA (AB3A Remanufacture), and finally as AH-64E Apache Remanufacture (AH-64E Remanufacture) in December 2012. Even with the multiple name changes, it remained the same acquisition program. The AH-64E New Build started in 2010 and was formed based on the 2009 Nunn-McCurdy outcome of the AH-64E Remanufacture program. The first name for the New Build program was Apache Block IIIB New Build (AB3B New Build) in 2010 and was changed to AH-64E Apache New Build (AH-64E New Build) in 2012.

final analysis. Our team addressed both of these perspectives in parallel as we determined our own portfolio analysis data and metrics. First, we will discuss those factors concerning ease of access, labor required, and applicability across our chosen portfolio.

Data Selection

We began by considering the characteristics of various data repositories and source documents to determine which would best support a repeatable, lower labor portfolio analysis methodology. Table 8.3 summaries our assessments of the various data sources.

Bearing in mind future users of our portfolio analysis methodology, we assessed data repositories by accessibility, applicability, timeliness, completeness, and required labor for data collection. The data repositories considered but not included were those listed below:

- **Service-Level Acquisition Databases**: These include the Army Acquisition Information Management (AIM); the Navy's Research, Development, and Acquisition Information System (RDAIS); and the Air Force's System Metrics and Reporting Tool (SMART). During our initial review of data sources, the team had access only to SMART, and it did not prove to be sufficient for our needs. However, it is possible that AIM and RDAIS contain data that would be useful in the completion of portfolio analysis projects.

Table 8.3
Information Systems and Selection Criteria

Database Selection Criteria	Service-Level Acquisition Databases	DCARC	AIR	DAMIR
Applicability of available data for portfolio metrics	Yellow	Yellow	Green	Green
Ease of data collection	Red	Red	Red	Green
Timeliness/completeness of data	Green	Yellow	Red	Green
Accessibility for RAND project team	Yellow	Green	Yellow	Green
Accessibility for OSD CAPE users	Green	Green	Yellow	Green

NOTES: Criteria used in the table above are RAND-defined. Each cell identifies whether a specific data source met that specific RAND criterion. Red indicates that the criteria were not fulfilled; yellow indicates that they were partially filled; green indicates that they were filled.

- **Defense Cost and Resource Center (DCARC)**: The DCARC portal includes an Earned Value Management (EVM) Repository and Contractor Cost Data Reports (CCDRs) in Defense Automated Cost Information Management System (DACIMS). Although DACIMS proved accessible to our target user set, the data within the system was far too granular for our metric needs. In addition, the downloading of large amounts of data on many MDAPs proved labor intensive.
- **Acquisition Information Repository (AIR):** During the study, this database was relatively new with limited access and incomplete documentation across the MDAPs within the portfolio. As the information system becomes more populated with documentation over time, it could serve as a useful source for understanding many additional details on the various MDAPs in the portfolio.

Because of its ease of access, consistent and complete documentation, and low labor cost in retrieving data, the team concluded that DAMIR served as the most appropriate database for the portfolio analysis. Table 8.4 displays the acquisition documents and DAMIR-generated reports available within the information system.

The team also assessed various data source documentation for similar criteria, including ease of access for the users, consistency and validation of data, and the regularity of data collection and presentation. Taking these into account, the team

Table 8.4
Documents Available in DAMIR

Acquisition Documents	DAMIR Data Captures
APB	SAR
SAR	SAR baseline
SAR baseline	DAES quarterly reports
DAES	DAES reliability growth curve
MAIS annual report (MAR)	DAES risk summary and issue summary
MAR original estimate	Historical critical change reports
Program Objective Memorandum (POM)	MAR
Budget Estimation Submission	MAIS quarterly report
Earned Value Analysis (EVA)	Sustainment metrics
	Better buying power goals and metrics
	Significant acquisition watchlist

NOTES: We define as *acquisition documents* any published document that has information on a program's development or performance. These documents are not necessarily available all years for all programs. The official acquisition documents have more consistent coverage across programs than do the DAMIR-generated documents. The data sources included in the table are of varying quality. For example, the data in SARs are generally considered of better quality than the data in the DAES reports. Finally, data sources that are both acquisition documents and captured in DAMIR are included in both columns.

concluded that SARs would serve as the primary source documents for data inputs. Congressionally mandated, the SARs are heavily vetted and produced annually, with occasional quarterly reports.[4] When SARs were not available for active MDAP programs, the team used DAES reports from December of the corresponding year to fill in gaps within the data. Submitted quarterly to the service-level acquisition databases and pulled into DAMIR, DAES include not only program status and assessment information by the program managers but also independent assessments by OSD and Joint staff stakeholders.[5] The team used DAMIR, SARs, and DAES for all of the portfolio cases, including the test case, helicopter, and satellite portfolios.

Metric Selection

Our portfolio analysis objectives—to identify and characterize cost and schedule risks—guided our selection of program and portfolio metrics. First, we wanted to comprehensively capture the different types of risk that might affect acquisition program cost and schedule outcomes because program outcomes may be affected by any number of types of risk. Second, we thought about program and portfolio indicators together, intending to select program data that we could then aggregate to the portfolio-level metrics. Finally, we wanted to identify and use existing data that were relatively easy to obtain consistently for all programs within the portfolio. It is worth noting again that our focus here was at the portfolio level. We wanted to select metrics that could be aggregated into portfolio-level views to provide insight into the performance of the portfolio overall. Portfolio-level metrics might not directly identify programs that need attention but can be used to view portfolio performance trends over time and to compare across portfolios.

The first step in our selection of program- and portfolio-level metrics was to define the types of risk and the specific outcomes that we wanted to include in our assessment. We focused on dimensions along which programs may experience problems, challenges, or setbacks that could affect program-level cost and schedule outcomes. These risk dimensions are listed in Table 8.5. We also identified descriptive indicators at the program level that would indicate outcomes of interest to the decisionmaker. It is important to note that some indicators, such as schedule change, quantity change, and cost growth, can result from multiple risk factors. There is no one-to-one correspondence between risk factors and individual indicators.

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[4] 10 U.S.C. §2432 outlines the requirements for SAR submissions, which are mandatory for all ACAT I programs. Program managers, through the DAMIR SAR module application, prepare SARs. Quarterly reports are submitted as major changes are observed in programs. SARs are annual unless reporting an APB or Nunn-McCurdy breach, in which case a program submits a quarterly SAR (in April, June, and September). Both SAR and DAES reporting begin at Milestone B, unless otherwise initiated by the MDA.

[5] DAES reporting usually begins once a program is initiated at Milestone B and ends after the program submits its final SAR. DAES is reported quarterly in three groups (A, B, and C).

Table 8.5
Candidate Types of Risk and Related Metrics

Risk Dimension	Definition	Potential Metric
Technical	Risk that originates from technology, development, integration, testing, or maturity issues	TRL levels Growth in RDT&E spending KPPs/KSAs met or unmet Testing failures
Political (external)	Risk that originates from political attention or events that may affect program funding, oversight, etc.	Nunn-McCurdy or APB breaches Program size Congressional mentions (testimony) Industrial base dispersion (i.e., how many states/districts is it produced in) Schedule changes Administration changes Military action/operations
Policy (internal)	Risk that results from policy changes affecting reporting requirements, program oversight	Program size (in dollars) Number of DAB- or MDA-level meetings[a] Number of acquisition documents required Number of waivers requested
Cost	Risk that results from cost growth, both unit cost growth and total cost growth	Unit cost growth/total cost growth Quantity changes
Funding	Risk that relates to the stability or amount of funding (as well as budget sufficiency)	Government budget changes Commercial/industry economic changes Budget sufficiency (do funds cover expected cost?) Percentage of funds remaining
Requirements	Risk related to the possibility that the program will not meet its current or future requirements and therefore not deliver needed capabilities	Schedule delays in operational or developmental testing KPPs/KSAs met or unmet Sustainment costs Age/maturity of program

[a] DABs are the senior advisory boards for defense acquisitions within DoD and are responsible for approving new MDAPs and for reviewing MDAP performance.

After reviewing all of these potential metrics, we selected a smaller set of descriptive program-level metrics, listed in Table 8.6, to apply to our test portfolio based on the following criteria:

- **Potential usefulness to decisionmakers**: We considered the types of information provided by each metric and aimed to include those metrics that provided the most valuable insight to policymakers about the status of the overall portfolio on multiple dimensions.

Table 8.6
Program- and Portfolio-Level Metrics

Program-Level Metric	Outcomes/Indicators Measured	Portfolio Metric
Descriptive-Type Metrics		
Size of program (dollars)	Cost outcomes, political (external) and policy risk	Average, median, standard deviation in dollar value
Percentage of funds remaining	Cost and schedule outcomes, overall risk	Average, median, standard deviation in percentage of funds remaining
Percentage of time remaining	Cost and schedule outcomes, overall risk	Average, median, standard deviation in percentage of time remaining
Latest milestone Achieved	Cost and schedule outcomes, overall risk	Percentage of programs passed Milestone B, Milestone C
Percentage change in quantity	Cost outcomes,overall risk	Average, median, standard deviation "Churn": average, median, standard deviation of absolute value of percentage change in quantity Percentage of programs with a quantity change over the previous year
Performance-Type Metrics		
Nunn-McCurdy or APB breaches	Cost, schedule, performance outcomes, political risk	Number of new breaches Cumulative total breaches Percentage of programs with at least one breach
Unit cost growth: percentage change in APUC or PAUC (current and/or original baseline)	Cost outcomes, funding risk	Average, median, standard deviation in PAUC/APUC growth from current baseline Percentage of programs with increase in percentage unit cost growth Distribution of percentage unit cost growth
RDT&E and procurement cost growth	Cost outcomes, technical and requirements risk	Average, median, standard deviation in cost growth
Percentage of KPP at or above threshold[a]	Performance outcomes, technical and requirements risk	Average, median, standard deviation of percentage KPP at or above threshold

[a] Unable to collect consistent data.

- **Consistency in reporting across programs**: We aimed to collect data generally available for all programs and all years of the analysis, rather than metrics that were missing for a large number of programs in the portfolios under consideration.
- **Comparability of descriptive metrics across programs**: We considered the meaning and calculation of metrics across programs and years and chose metrics that provided identical types of information across programs over metrics that

were calculated in different ways or had different meaning for different programs or in different years.

- **Availability of data to the RAND team and decisionmakers**: We tried to choose data sources that were unclassified, that were easily accessible using standard databases, and that did not require special access.
- **Ease of gathering and recording data**: We considered the difficulty of data collection, the number of different documents and sources that needed to be obtained or consulted, and the number of transformations or calculations needed to get the data into usable form.

These criteria limited our metrics to those that were reported in or could be calculated from annual or quarterly SARs or quarterly DAES reports. We found that these reports had the most consistent and reliable reporting formats over time and between programs and were accessible to all analysts with access to DAMIR. In determining potential usefulness to decisionmakers, we focused on data that reported cost and schedule performance outcomes for the program or provided an indicator of risk exposure (technical, cost, policy, or overall risk).

In our original framework, described at the start of this chapter, we developed portfolio metrics by rolling up program metrics and aggregating them to describe the overall status of an entire set of programs, rather than the status of a single program. For example, although percentage change in unit cost is a metric that we would want to observe at the program level, at the portfolio level, we are interested in such metrics as the mean and median in percentage change in unit cost across a set of programs. Many past performance assessments focus more exclusively on program-level metrics and fail to take the larger, portfolio view into account. However, a notable exception is DAMIR's relatively new "portfolio view," which provides snapshot views of several metrics across a variety of defined portfolios. Table 8.7 provides a summary of this tool within DAMIR.

Table 8.7
Portfolio Views Within DAMIR

Portfolio	Dashboard (SAR and DAES Data Visualization)

Services (Army, Air Force, Navy) and DoD DAES Group (A, B, C) Acquisition program (C3I, MAIS, MDAP) Status (active, inactive, all) Type (aircraft: bomber, C3I, fighter, other, transport, UAS; C3I; combat vehicle; helicopter; missile; munitions; radar; satellite; ship; submarine; transport vehicle)	Contractors Contract location Contract performance Current estimate by appropriation Current cost variance changes by appropriation Funding overview by service Funding projection total by appropriation Total funding by commodity Total funding by program Program with most funds remaining Program phase by milestones Program status by service Sunk cost Unit cost by percentage change

By explicitly defining and focusing on portfolio metrics, our methodology shifts to a higher level of analysis and provides a different perspective on portfolio assessment. In developing the portfolio-level metrics, listed in Table 8.6, we also considered the types of assessments that these metrics might be used for. The selected metrics allow for the following types of assessments:

- assessment of portfolio status on a single metric
- integrated assessment of portfolio status on multiple metrics
- a static "point-in-time" assessment of a portfolio or subportfolio
- comparisons of portfolio or subportfolio status over time (for year-on-year, or longer-term trends)
- comparisons of portfolio composition.

The data we collected fit our criteria for consistent reporting, comparability across portfolios, and availability and ease of collection. In addition, the resulting metrics each provided specific information useful to policymakers when surveying a single program as well as a larger portfolio. Although the metrics by themselves can provide useful information, it is when these are integrated that a policymaker receives a more nuanced view of the portfolio. We describe each metric below, as well as key relationships between them.

The metrics selected fall into two major, interrelated categories: *descriptive* and *performance*. Descriptive metrics that outline characteristics of a program or portfolio help provide context for the performance metrics. For example, we considered program size, in terms of total program value or cost. Very large programs in terms of total cost (e.g., Joint Strike Fighter [JSF]) may have more political importance, visibility, and therefore more "weight" within the portfolio as a whole. In addition, percentage unit cost growth alone does not provide enough information to understand the relative influence of different programs on the portfolio. Cost growth of 5 percent for a program such as the JSF with a total program cost upward of $270 billion would affect

the overall status of the portfolio more than the same percentage cost growth for a $17 billion program such as Excalibur. To account for this, we included metrics for total program cost at the program level; and at the portfolio level, we examined the average, median, and standard deviation of total program cost. Finally, larger programs in terms of total cost may also garner more political or external scrutiny leading to a higher level of program risk.

Other descriptive-based metrics provide insight into a program or portfolio's overall exposure to risk. In this vein, we examined four metrics: percentage of funds remaining, percentage of time remaining, latest milestone achieved, and percentage change in quantity. Changes in portfolio median for the percentage of funds and time remaining may indicate portfolio maturity and stability. One might assume that a more mature portfolio could have a lower level of future risk as a result of program stability and development. A similar observation can be made about the percentage of programs in a portfolio that have passed Milestone C. Before Milestone C, programs are still in the development and testing phase—the phase when most of the technical, integration, and manufacturing issues that can affect program cost and schedule arise. After Milestone C, programs typically entered LRIP,[6] and overall program risk type changes from primarily technological or developmental to primarily production or production-related. When normalizing for quantity changes in procurement, most studies find that procurement cost growth is lower than development cost growth.[7] A greater percentage of post–Milestone C programs indicate a more mature portfolio.

Finally, changes in quantity are an indicator of program stability. Large or frequent quantity changes in either the positive or negative direction can be an indicator of program performance, political support, fluctuating operator requirements, or other program issues. Instability in quantity can also affect cost growth risk; prior analysis has found that up to 21.9 percent of cost growth for MDAPs can be explained by program quantity changes.[8] At the portfolio level, measuring the size and frequency of program quantity changes can indicate portfolio stability. However, it is also worth noting that changes in quantity are not, in and of themselves, indicators of a problem within the affected program. For example, a large increase in quantity for the Tomahawk missile in 2011 reflected not a program failure but instead an increase in demand during the Libya crisis.[9] This observation is an important one that also applies to other metrics. In many cases, it is difficult to interpret, out of context, whether the value of a given metric is a sign of increased risk, problems within a given program, or an external

[6] LRIP can be entered before Milestone C in some cases and is not always mandatory.

[7] As described in Joseph G. Bolten, Robert S. Leonard, Mark V. Arena, Obaid Younossi, and Jerry M. Sollinger, *Sources of Weapon System Cost Growth: Analysis of 35 Major Defense Acquisition Programs,* Santa Monica, Calif.: RAND Corporation, MG-670-AF, 2008, p. xvi.

[8] Bolten et al., 2008

[9] "Raytheon's Tomahawk in Demand," Zacks Equity Research, June 11, 2012.

factor affecting the program. Instead, most metrics flag possible problems that require additional investigation before they are interpreted one way or the other.

As stated, the aforementioned metrics provide a degree of context for the more performance-based metrics, which focus on schedule and cost growth status or outcomes. Cost growth is arguably one of the most closely monitored performance metrics by managers as an indicator of program success or failure. It can be driven by a range of factors, many of which relate directly to the risks programs are managing, including technical difficulty, underestimation of technological maturity or system integration challenges, and poor estimation of cost inputs (labor, materials, infrastructure needs), among other factors. A brief discussion of the interpretation of cost metrics at the program and portfolio levels provides insight into how program metrics, portfolio metrics, and portfolio risk and status fit together. In general, upward trends in program or portfolio unit cost metrics over time can be an indicator of increased portfolio risk. Cost growth in specific programs within a portfolio affects the overall status of that portfolio and provide an indication of risk within the portfolio—risk of additional cost growth, possible cost or schedule breaches, possible funding issues, and other possible concerns. Cost growth at the portfolio level, then, signals policymakers and acquisition executives that additional inquiry is required to diagnose the source and meaning of any possible problem.

For our unit cost metrics at the program level, we chose to focus on the current baseline metrics for PAUC and APUC because the original baselines were not consistently reported in the SARs over the time period 2002 to 2012.[10] In addition, the current baseline reflects any changes in the program that required the establishment of a new APB. In this regard, we made the assumption that if a program had rebaselined, then issues that affected cost and schedule risk would be addressed at that time and the current baseline would reflect the current status of the program. At the portfolio level, we examined the average, median, and standard deviation of unit cost growth over time and tested for statistical significance.[11] We also examined the percentage of programs with increases in unit cost growth and the distribution of cost growth to provide an indication of the variation in cost performance within the portfolio.

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[10] Statutorily mandated reporting of the original baseline in the SARs did not begin until 2006, and at that point, some programs reported the current baseline as the original baseline and some programs reported the original APB as the original baseline. Additional discussion on the issue and effects of rebaselining can be found in the next section and in more detail in Mark V. Arena, Irv Blickstein, Daniel Gonzales, Sarah Harting, Jennifer Lamping Lewis, Michael McGee, Megan McKernan, Charles Nemfakos, Jan Osburg, Rena Rudavsky, and Jerry M. Sollinger, *DoD and Commercial Advanced Waveform Developments and Programs with Multiple Nunn-McCurdy Breaches, Volume 5*, Santa Monica, Calif.: RAND Corporation, MG-1171/5-OSD, 2014a, pp. 101–105.

[11] The average and median are measures of central tendency, that is, the values where most of the data appear to be clustered. The average is equal to the sum of all observations divided by the number of observations, and the median in the value exactly in the middle of the distribution. The standard deviation measures the spread or dispersion of the data. Statistical significance is a measure of how meaningful a given set of results is. It assesses whether the observed results or values are likely to be due to chance or represent a meaningful trend in the data.

We also examined total RDT&E and procurement cost growth as components of total cost growth. The RDT&E cost growth component was selected as an indicator of technical risk in the program; unanticipated increases in development costs are often due to technical factors or technology requirements instability. An increase in the portfolio median for this metric might indicate technical or integration issues, or such nontechnical issues as requirements instability or inaccurate cost-estimating assumptions.[12] We would expect RDT&E cost growth to be higher in portfolios with more pre–Milestone C programs or those that are less mature (i.e., fewer average years past Milestone B). Procurement costs include the recurring and nonrecurring costs associated with the production and initial support of the system.

Commonly used metrics—Nunn-McCurdy and APB breaches—are often lagging program indicators, that is, breaches often occur after the program has encountered problems. A program may have a significant or a critical Nunn-McCurdy breach in APUC or PAUC. These breaches are measured also against the original and current baselines.[13] In addition, in any given year, a program may have an APB breach in one or more of eight categories.[14] These breaches trigger a series of review, reporting, and certification activities that may result in program redirection, restructure, or termination. At the portfolio level, the percentage of programs that have breaches can signify the status of the portfolio in the given year.

In addition to collecting information on cost and schedule growth, we attempted to collect consistent data on the percentage of key performance parameters (KPPs) that were at or above threshold as an indicator of portfolio performance and technical risk. However, data on KPPs were not consistently reported (in SARs and DAES) across services and programs, and thus we were unable to develop a valid indicator at the portfolio level. Also, past RAND research found performance metrics to be "insufficient proxies" of technical risk and difficulty as certain performance indicators may carry more influence than others or the sample may contain incomparable, unlike items.[15]

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[12] Further details on these issues can be found in Bolten et al., 2008; and Obaid Younossi, Mark V. Arena, Robert S. Leonard, Charles Robert Roll, Jr., Arvind K. Jain, and Jerry M. Sollinger, *Is Weapon System Cost Growth Increasing? A Quantitative Assessment of Completed and Ongoing Programs*, Santa Monica, Calif.: RAND Corporation, MG-588-AF, 2007.

[13] A "significant" breach occurs when APUC or PAUC increases 15 percent or more over the current baseline estimate or 30 percent or more over the original baseline estimate. A "critical" breach occurs when APUC or PAUC increases 25 percent or more over the current baseline estimate and 50 percent or more over the original baseline estimate.

[14] These APB categories are schedule, performance, RDT&E cost, procurement cost, military construction (MILCON) cost, O&S cost, PAUC, and APUC. APB breaches occur when a program exceeds the baselines set in the APB document, which defines the targets for cost growth, performance, and schedule. Specific definitions are provided in Chapter Nine.

[15] See Jeffrey A. Drezner, Jeanne M. Jarvaise, Ron Hess, Daniel M. Norton, and Paul G. Hough, *An Analysis of Weapon System Cost Growth,* Santa Monica, Calif.: RAND Corporation, MR-291-AF, 1993. See also Edmund

As noted in the previous chapter, the set of metrics we include in this methodology is only one of many possible sets that could be used to assess portfolio performance. We intentionally chose about ten metrics that cover key aspects of portfolio performance, believing that this number can provide diverse and varied insights without becoming overly complicated and complex for analysts and decisionmakers. Analysts may choose to focus on a smaller subset of these metrics when it comes time to actually present insights to policymakers or may incorporate other metrics that address specific questions of interest. Also stated above, one must understand the interrelationships among the metrics to create a more holistic picture of the portfolio and adequately explain observed patterns and trends. Taken together, multiple metrics provide context and clues as to the root causes of unusual or interesting trends.

Addressing Data Anomalies and Challenges

While collecting data, we came across a number of data anomalies, including missing data, programs that split or changed with the addition of new blocks or modifications, and programs that rebaselined during the assessment period (affecting unit cost and quantity calculations). Many of these issues arose during the test case portfolio data collection, and the assumptions made to address those were carried over to the helicopter and satellite portfolio data collection. To maintain an auditable product, analysts performing their own portfolio analysis will need to carefully track these anomalies and the assumptions or measures they took to address these. To describe the data anomalies and how we addressed them, we provide here a short background on the programs included in the test case portfolio and the data issues that arose.

Our test case drew on previous RAND research for OSD that had developed an approach to anticipating Nunn-McCurdy breaches.[16] This approach reduced a list of approximately 100 MDAPs into a more manageable "watch list" of programs that should be monitored more closely for possible breaches. We used this watch list as our test case to identify important data issues and challenges that analysts would need to overcome to complete a portfolio assessment (see Table 8.8).[17]

Dews, Giles K. Smith, Allen A. Barbour, Elwyn D. Harris, and M. A. Hesse, *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s,* Santa Monica, Calif.: RAND Corporation, R-2516-DRE, 1979.

16 Arena et al., 2014b.

17 We used this as the test case for two primary reasons. First, many of the data had already been collected, allowing us to focus on the methodology not the data collection. Second, this portfolio included a variety of programs that are representative of all of the services and different commodity types. This allowed us to see if there were consistencies in how data were reported across services and commodities and to identify data issues that might affect how portfolio metrics are reported. Finally, these programs were on the "watch list" because they appeared more likely than other MDAPs to experience a breach on more dimensions. For example, some had experienced a previous APB or Nunn-McCurdy breach. Others had periods of high and rising cost growth or had experienced significant production delays. As a result, the programs in our test case portfolio could be considered "high

Table 8.8
Initial Test Case Programs; 2010 Watch List

Joint Program
Airborne and Maritime/Fixed Station (AMF) Joint Tactical Radio System (JTRS)
Chemical Demilitarization-Assembled Chemical Weapons Alternatives (Chem Demil-ACWA)
Handheld, Manpack and Small Form Fit (HMS) JTRS
JSF
Joint Tactical Networks (JTN)
Air Force Program
AEHF
Advanced Medium-Range Air-to-Air Missile (AMRAAM) Air Launch Aerial-Intercept Guided Missile 90 (AIM-90)
Family of Advanced Beyond Line-of-Sight Terminals (FAB-T) Increment 1
Global Hawk (RQ-4)
GPS IIIA
Joint Air-to-Surface Standoff Missile (JASSM) (Baseline)
NAVSTAR GPS
Reaper (MQ-9)
SBIRS-High
WGS
Army Program
Integrated Air and Missile Defense (IAMD)
Excalibur
Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)
Patriot (PAC-3)
Navy Program
AIM-9X
CH-53K
Guided Missile Destroyer (DDG) 100
E-2D Advanced Hawkeye (AHE)
H-1 Upgrades
Littoral Combat Ship (LCS)
Landing Helicopter Assault (LHA) 6
Landing Platform Dock (LPD) 17 Class
MH-60S
Remote Minehunting System (RMS)
Tomahawk
Virginia-class (SSN 774)
Vertical Takeoff and Landing Tactical Unmanned Air Vehicle (VTUAV)

SOURCE: Arena et al., 2014b.

risk" relative to other MDAPs. By selecting this test portfolio, we intended to observe how our selected metrics reflected this portfolio risk.

Data Anomalies and Challenges Within the Test Case, "Watch-List" Portfolio

Although the test case portfolio is covered in more detail in Appendix B, we discuss here some of the data challenges we faced during our test case analysis to make some broader observations about the challenges and considerations analysts may face during a portfolio analysis. As noted above, the watch list portfolio consisted of 32 programs active in 2010 and 2012 and represented a variety of commodity types across the services.[18] We discovered during data collection that certain metrics applied differently, or not at all, across commodity types. This is likely to be true for any portfolio of programs and is an important factor that must be taken into account during the portfolio analysis process. In each case, these anomalies must be dealt with program-by-program, and analysts may also need to consider alternative metrics that provide insight into the status of nontraditional programs. For example, Chem-Demil-ACWA is essentially a service, not a physical product, thus precluding the use of metrics derived from quantities. It also does not follow a typical acquisition schedule path, so its scheduling data would not be congruent with other MDAPs within the portfolio. The JTN and the NAVSTAR GPS User Equipment programs also did not include quantities, inhibiting the calculation of metrics that depended on this variable (for example, unit cost). In addition, many of the programs' SARs, especially the satellite programs, did not explicitly state estimated milestone achievement dates within the schedule sections. In these cases, the team recorded milestone achievements based on the acquisition activities completed by the SAR's date, such as contract awards and engineering or production decisions.

The fact that our portfolio compared multiple years presented additional challenges as programs introduced new increments or blocks, split into separate programs, were cancelled, or completed their SAR reporting. These challenges are almost certain to emerge in any portfolio analysis. In dealing with these types of program and portfolio changes, the most important considerations are consistency and transparency. Analysts should make explicit and clear the ways in which they choose to treat each program and be sure to apply a consistent set of rules to all programs within the portfolio. For instance, the AEHF program was a single block under one program number (PNO) in 2010; however, in 2012, the program comprised two blocks (SV 1-4 and SV 5-6) with disaggregated data, although under the same PNO. AIM-9X Block I, under PNO 581, ended in 2011 and was followed by AIM-9X Block II, PNO 442, in 2012. A summary of all of these issues found during the watch list portfolio data collection is in Table 8.9. We discuss the assumptions made to address these challenges in a subsequent section.

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[18] It is worth noting that the number of programs in the test case portfolio is likely larger than optimal for this methodology of portfolio assessment. However, we chose to use this as the test case anyway for the data availability, range of different programs, and "higher risk" profile (see footnote 17). Because the test case was used as a tool for methodology development, we felt that this decision was justified.

Table 8.9
Summary of Test Case Portfolio Data Issues

Issue	Program Affected	Notes
Program begins/ends during portfolio time frame	AIM-9X Blocks I & II	AIM-9X Block I stops reporting by 2012 because it is over 90 percent complete; Block II begins reporting in 2012
	Reaper (MQ-9)	Reaper did not report an APB in 2010 because it had just transitioned from ACAT II to ACAT I because of increased funding
Program split into separate blocks/increments under same PNO	Advanced EHF	Data are reported separately for Satellite Vehicle (SV) 1-4 and SV 5-6 in 2012
	JASSM	Data are reported separately for JASSM Baseline and JASSM-ER in 2010 and 2012
	JSF	Data are reported separately for the F-35 aircraft and engine in 2012
	NAVSTAR GPS	Data are reported separately for satellite and control and user equipment in 2010 and 2012
	SBIRS-High	Data are reported separately for the Baseline and Block Buy in 2012
No quantities noted	Chem-Demil-ACWA	Nature of program (service-based)
	JTN	Nature of program (software-based)
No milestone noted	Chem Demil-ACWA	Nature of program
	FAB-T	Acquisition activities listed, but milestones not explicitly listed in schedule
	Global Hawk	Acquisition activities listed, but milestones not explicitly listed in schedule

Data Anomalies and Challenges Within the Satellite and Helicopter Portfolios

Many of the data issues that emerged in the test case portfolio also proved problematic in the satellite and helicopter portfolios (see Table 8.10). However, we faced an additional challenge with the satellite and helicopter portfolios, because of changes in portfolio composition over the 11-year time frame of our investigation. In our analysis, a program leaves the portfolio when it is completed or cancelled. Defining when a program enters the portfolio is somewhat less straightforward. Because SARs were the primary data source, we decided to define "portfolio entry" as when a program first began reporting SARs. This is typically when a program enters Milestone B, although some programs begin reporting earlier (e.g., DDG 1000, F-35). Because programs were constantly moving into and out of the portfolio, we had to pay more careful attention to changes in composition as we calculated and interpreted portfolio metrics. These changes in composition are not a problem per se, but they are considerations that need to be taken into account as metrics are calculated and interpreted.

The second data issue that arose during our data collection for the satellite and helicopter portfolios—one that was not addressed during the test case analysis—involved the availability of SARs in 2008. We discovered that DAMIR had very few SARs posted for that year and, thus, we relied on the DAES most equivalent to the

Table 8.10
Data Issues in Satellite and Helicopter Portfolios

Issue	Program Affected	Notes
Program begins/ends during portfolio time frame	CH-53K	Began reporting in 2004
	Comanche	Stopped reporting in 2004
	Longbow Apache	Stopped reporting in 2011
	ARH	Began reporting in 2005, stopped reporting in 2009
	VH-71	Began reporting in 2005, stopped reporting in 2009
	LUH	Began reporting in 2006
	AH-64E New Build	Began reporting in 2010
	AH-64E Remanufacture	Began reporting in 2006
	MUOS	Began reporting in 2004
	GPS III	Began reporting in 2008
	GPS OCX	Began reporting in 2012
	NESP	Stopped reporting in 2005
	NPOESS	Stopped reporting in 2012
	SBSS Block 10	Began reporting in 2007, stopped reporting in 2011
	TSAT	Reported only in 2004
Program split into separate blocks/ increments under same PNO	SBIRS-High	Data are reported separately for the Baseline and Block Buy in 2012
	NAVSTAR GPS	Data are reported separately for satellite and control and user equipment in 2010 and 2012
	Longbow Apache	Data are reported separately for airframe modifications and FCR mission kit in 2002 and 2003
No quantities noted	Not applicable	Not applicable
No milestone noted	GPS III	Uses “key decision points”
	MUOS	Uses “key decision points”
	NAVSTAR	Reports by production segments
	SBSS Block 10	Uses “key decision points”
	TSAT	Uses “key decision points”
No 2008 SARs	All except H-1 Upgrades	In 2008, SARs were not necessarily submitted; instead, PB2010 Limited SARs were submitted, which are not included within DAMIR

December SAR.[19] The GAO encountered a similar problem during this time frame, stating that it "did not analyze the cost and schedule performance of the [2008] portfolio because DoD did not issue timely or complete Selected Acquisition Reports for the second consecutive presidential transition."[20] After Congressional protest, the administration submitted "PB2010 Limited" SARs; however, these did not contain the same level of budgetary information and were not considered "official," so they are not available with the DAMIR information system.[21]

Assumptions Made to Address Anomalies

To maintain consistent data collection and cleaning, we relied on a number of assumptions to address data anomalies. We used the same assumptions across the test case and satellite and helicopter portfolios. These "rules" establish a repeatable process that allows for comparison across all programs and portfolios and are listed in Table 8.11.

Finally, in addition to these common issues and mitigating assumptions, we also had to develop a strategy to deal with unique issues, such as software programs, whose characteristics make certain metrics not applicable. For these programs, we simply

Table 8.11
Mitigating Assumptions to Address Data Anomalies

Common Data Issue	Mitigating Assumption
Determining when to begin and end data collection over the time frame of portfolio analysis	Begin and end collection of data based on when the program is reporting SARs
Program split into separate blocks/increments/components under same PNO	Combine subprograms and components into a single program, collecting cumulative data when applicable
Program split into separate blocks/increments under different PNOs	Consider blocks/increments/components as separate programs
No quantities noted	Record data entry as "non-applicable" and do not include program in that metric's analysis
No milestone noted	Using listed acquisition activities under the schedule, apply DoDI 5000.02 guidelines for assigning an appropriate "milestone achieved" code during the year of data collection
Data not reported in SARs, or SARs unavailable for a given year	Although not as heavily vetted as SARs, the DAES offer another source for many of the metrics; the use of an alternative source should be noted
Generally missing data with no identifiable alternative sources	In some cases, interpolation or calculation from congruent data may be appropriate, but if this is not possible, the data entry will be labeled as "missing" and not included in the overall analysis

19 Different programs may report in different months, so we had to use DAES reports from several months (October, November, and December).

20 Government Accountability Office, *Defense Acquisitions: Assessments of Selected Weapon Programs,* Washington, D.C., GAO-10-388SP, March 2010.

21 From discussions with DAMIR personnel.

record "not applicable" for the affected metrics. This is one limitation of our methodology as it means that our assessment will not capture the performance or status of these programs. To address this limitation, an assessment phase of the analysis would need to incorporate additional and higher-level metrics that capture the effect of these programs on the portfolio. It is important to note that these types of program-specific issues will affect any portfolio under consideration. Each program has unique characteristics, some of which make certain metrics difficult or meaningless. For these programs, we apply our business rules as consistently as possible across programs, and we make all assumptions and adjustment explicitly, allowing a reader to clearly assess how we have approached the analysis to disagree with or modify our assumptions if desired.

Additional Data Considerations

Data collection for the portfolio analysis includes not only recording relevant metrics and addressing the data issues described above but also processing the data to ensure that they are comparable across years and programs. For example, data concerning funds require conversion to constant year dollars to account for inflation. In addition, defense acquisition programs often rebaseline—a process that can confound the benchmark against which metrics are calculated. Therefore, we collect data on and track cost and quantity changes based on the original baseline as well as the new baseline.

Calculating Portfolio Metrics and Statistical Significance

After collecting our selected program metrics, the next step was to calculate the aggregated portfolio metrics described above. Analysts will need to consider how they wish to compile and package the data collected in terms of the portfolio type as well as the defined objectives of the portfolio analysis itself. As noted above, the portfolio metrics we selected are intended not to summarize the status of a single program but to provide a higher-level assessment of the portfolio based on the status of the programs included in that portfolio. Different portfolio metrics provide information on different aspects of the portfolio. Because our intention was to develop a repeatable methodology that could be applied to portfolios of all kinds, we spent considerable time developing a generalizable computer program that can easily calculate portfolio metrics.[22] This same program can be used to calculate metrics for the satellite and helicopter portfolios and will be equally applicable to other, larger portfolios with more years of data.

As noted in Table 8.6, the portfolio metrics that we calculated included mean, median, and standard deviations of such quantities as percentage unit cost growth, quantity change, total program value, and percentage of RDT&E and procurement

[22] The generalized computer program was developed in STATA, a statistical package used to conduct data analysis.

funds remaining. We also counted the number and types of breaches and the number of programs past key points in development, such as Milestones B and C. Each of these portfolio metrics gave us a unique window on the status of the portfolio. Furthermore, these metrics can be combined and viewed together to provide a more holistic view of portfolio status.

In addition to looking at static portfolio metrics to assess the status of our test case programs in each year, we also hoped to compare across years to understand how the portfolio changed over time. This involved not only calculating metrics but also determining whether changes we observed between years were statistically significant (meaning that we can say with a given level of confidence, usually 95 percent, that the observed change is statistically different from zero or that the change is a real change in the trend and is not simply noise in the data) and substantively meaningful (or sizable enough to suggest a meaningful change over time). To address statistical significance in the test case with only two years of data, we relied on paired t-tests for unweighted data. This made sense in the context of our test case portfolio in which all programs are the same in the two years. The paired t-test takes this program consistency into account. The t-test compares the difference between the means of the two samples (2010 and 2012) to the variance within each sample independently, taking into account the number of observations. When this ratio value is large (greater than two), then the difference between the two years is said to be statistically significant and is unlikely to be due to chance.

For the satellite and helicopter portfolios, however, we needed a different way to assess statistical significance because we had so many more years of data. In these instances, we conducted a number of tests. First, we used a fixed-effects model, which is able to account for program-specific characteristics (essentially includes a control variable for each program in the analysis). The fixed-effects model allows us to determine whether observed differences in portfolio performance between any two years are statistically significant, meaning that we can say with some certainty that they are different from zero or that the change is a real change in the trend and is not simply noise in the data. For example, we can use the results of the model to determine if a difference in unit cost growth between 2004 and 2005 is statistically meaningful or likely to be due to chance. We can conduct these paired comparisons for all pairs of years and for each metric. We can also use the overall fixed-effects coefficient to provide a summary measure of the change over time, on average, as well as the significance of that change.

In addition to statistical significance, we are also interested in the substantive importance of a given effect. Even if an effect or observed change is statistically significant, we may not care about that change if it is substantively small or insignificant. For substantive importance, we used a measure known as Cohen's D, which also compares the difference between the means of the two sample years and the differences or variation within each year. When this value is large (greater than 0.7), it suggests a substan-

tively meaningful difference. However, when the value is very small (less than 0.2) the associated effect size is not very meaningful. When the value is between 0.2 and 0.5, we can say that the substantive importance is small, and when the value is between 0.5 and 0.7, the effect size is moderate.

In addition to calculating each metric, conducting significance tests, and considering substantive importance, we also conducted some additional calculations to address anomalies within the data and to incorporate program size as a measure of program influence. To address outliers, we conducted all analyses both with and without certain programs that seemed to lie far from the rest of the data. The best examples of this occurred in our test case portfolio, where we calculated the total program value metrics with and without the JSF program (the largest program by far) and the PAUC metrics (mean, median, and standard deviation) with and without JLENS. Although we do not want to ignore these programs in our assessment, we also want to understand patterns and relationships within the data that might be hidden by the inclusion of the outlier.

We also took additional steps to incorporate program size into our calculation of metrics, calculating all the metrics using both unweighted and weighted data, employing program value as the relevant weight. By doing this, we address the fact that the status of the largest programs in the portfolio may be most important to policymakers. A given percentage unit cost growth, for example, will be most significant when it occurs in a large program. Similarly, breaches and variability in quantity may be most problematic when they occur in large programs.

Visualizing Portfolio Metrics

Calculations of metrics, although useful for the analyst, must be properly packaged in a way that is digestible for the policymaker. Although the preferences of the policymaker may vary from Excel sheets to narrative forms, data visualizations may be necessary to quickly indicate implications and relationships between the portfolios and their inputs. To analyze the portfolio metrics that we calculated, we developed a series of visualizations to display the data. Table 8.12 shows a list of the visualizations used and the information that each is intended to provide. In our portfolio analysis of the helicopter and satellite portfolios, we present all of these visualizations and metrics for each portfolio. However, in reality, it might be too time consuming for an analyst to develop the full set of visualizations for all portfolios or for a policymaker to digest the information presented by many different visualizations for many different portfolios. Using Table 8.12, however, the analyst could choose to complete the specific visualizations that address policymaker questions, thus tailoring the analysis to the issues of interest. Furthermore, it is worth noting that these visualizations highlight portfolio-level trends. Additional analysis might be required to identify specific programs with

Table 8.12
Visualizations and Information Provided

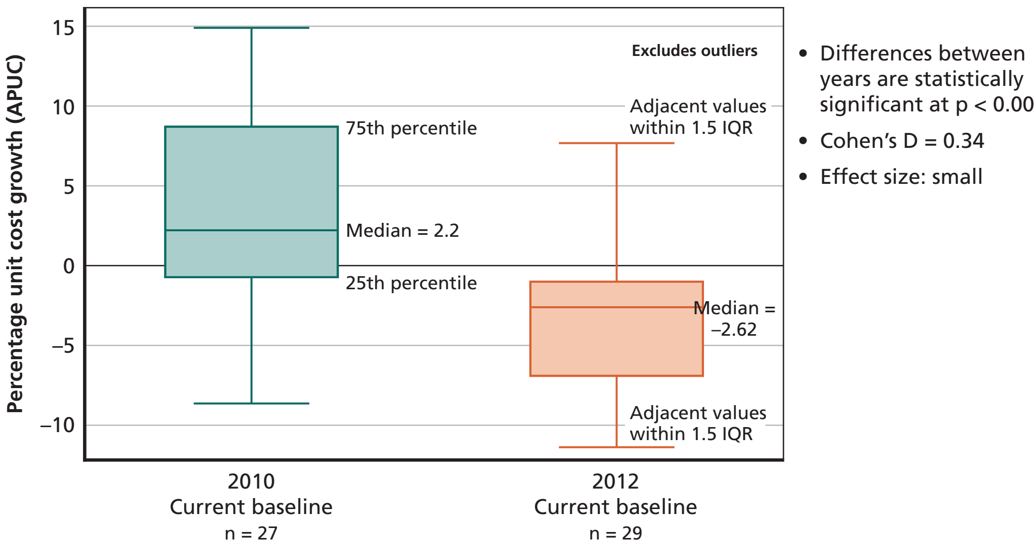
Visualization	Type of Information Provided
Histograms and bar charts	Distribution of programs Trends in numerical metrics
Box-and-whisker plots	Medians and change over time Range and spread of data (with or without extreme values)
"Heat" map	Year-on-year changes across the portfolio for one metric More detailed view of program-level information
Bubble diagrams	Two metrics displayed simultaneously A measure of a program's "influence" in portfolio One way to visualize a weighted metric
Radar charts	Aggregate view of several different metrics at one or several points in time

high levels of risk or poor performance. Bar charts were used mainly to display descriptive information about the portfolio—for example, number of programs by milestone, number of programs by service, or number of programs by DAMIR category (i.e. logistics, force application, etc.). These bar charts allowed us to analyze portfolio composition over time.

Box-and-whisker plots were used for metrics where the median and standard deviation were calculated; these metrics included unit cost and program funding metrics. The box-and-whisker plots display the statistical distribution of the data including the median, the degree of dispersion (spread), and the range of the data. An example of a box-and-whisker plot for the test (watch list) portfolio is displayed in Figure 8.1. The box represents the data that fall within the 25th and 75th percentiles (the middle 50 percent of the data) called the interquartile range (IQR). The height of this box represents how dispersed those data are. The bars that extend outside of the boxes are called "whiskers," and they provide a measure of the range of the data, connecting the adjacent values 1.5 times the IQR above and below the median. Data points that lie outside this range are sometimes represented as dots but are sometimes omitted from the graph for presentation purposes. Finally, we include with our box-and-whisker plots a measure of effect size, using Cohen's D as defined above

Another visualization technique that we used to display year-on-year portfolio data for a single metric is a "heat map." A heat map is a graphical representation of data where individual values or ranges of values are represented by colors. Heat maps are useful for highlighting key trends over time. In many of these charts, a "trend to green" suggests a general improvement in performance (where red is poor performance and green represents good performance). We applied this graphical representation to the unit cost metrics for the helicopter and satellite portfolios to display portfolio performance between 2002 and 2012. Programs with no shading indicate that the program

Figure 8.1
Example Box-and-Whisker Plot; Test Portfolio percentage Change in Current APUC, 2010 and 2012



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is not reporting in that year or has been cancelled. This display allows the decision-maker to make comparisons on a single metric across years (when viewed from left to right) and programs (when viewed from top to bottom).

The visual displays we have discussed up to this point are useful for displaying one metric over time or across programs. However, there may be cases where we would like to assess program performance along several different dimensions simultaneously. We found that, for example, in our display of PAUC and APUC data, we were able to identify poorly performing programs within the portfolio, but we were missing the substantive influence, or relative "weight," of that program to the portfolio. A very large program (in terms of total program cost) that is performing poorly may have more of a negative effect on overall portfolio status than a relatively small program. To indicate the relative weight of programs in the portfolio we used bubble chart displays. Bubble charts are used to show relationships between three variables. The area of the bubble represents the relative size of the program in terms of estimated total program cost, and the position of the bubble marks the APUC and PAUC for the program in a given year. Programs in the upper right quadrant are poorly performing programs from a cost perspective, whereas programs in the lower left quadrant are performing better.

Finally, we also used radar charts to display multiple portfolio metrics on one plot. These radar charts allow the user to get an aggregate view of portfolio status across periods of time. We provide examples of both approaches in our analysis of the helicopter and satellite portfolios in subsequent chapters.

It is possible to display more or fewer metrics on the radar depending on the portfolio characteristics that the decisionmaker is interested in. For our analysis, we selected six metrics that offer insight into portfolio status. Past data suggest that a larger portion of a program's cost growth occurs in the pre–Milestone C phase; thus, if there are a larger percentage of post–Milestone C programs in the portfolio, the portfolio might be considered lower risk. In the same regard, quantity changes (both positive and negative) have historically had an effect on program cost growth; therefore, the more programs in a portfolio with quantity changes in a given year, the less stable a portfolio might be.[23] In terms of APB and Nunn-McCurdy breaches, the radar plots indicate the percentage of programs in a portfolio with any breach in the given year. A program may have three APB breaches in one year, but it would be counted only once for the purpose of the portfolio display.[24] Finally, the PAUC and APUC metrics are intended to capture the poorly performing programs presented in the heat maps (programs in shades of red). On the radar plot, we indicate the percentage of programs in the portfolio that have greater than 5 percent growth in PAUC or APUC from the current baseline in the given year. Some caution needs to be taken when interpreting these charts from year to year on a single dimension, as the number of programs in the portfolio often changes from year to year. Thus, the same number of programs may be performing poorly from year to year but the shape may appear to shrink if a new program is added that is performing well.[25]

Examples and interpretation of all these visualizations will be provided in subsequent chapters.

Chapter Summary

This chapter outlined our portfolio analysis framework, which included the following steps: identify objectives, choose portfolio type, select data and metrics, address data anomalies and challenges, calculate metrics, and visualize metrics. In selecting portfolios for analysis, we focused on choosing portfolios that would offer robust tests of our methodology and would allow us to refine these methodologies as necessary. In selecting metrics, we chose a set that would comprehensively assess program and portfolio status and capture many cost and schedule dimensions of program and portfolio risk and status. We also discussed the visualizations that we used to present the results of our analysis and provided examples of these visualizations and their interpretation.

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[23] Bolten et al., 2008.

[24] This is a function of how we have defined the metrics included in the radar plot.

[25] For example if four of eight (50 percent) programs have APB breaches in 2010 and then a new program is added in 2011 that has no APB breaches, the radar chart will appear to shrink (44 percent) on the APB dimension.

Finally, we used a set of visualizations that graphically summarize our analysis in a way that may be useful and intuitive for policymakers. In the next chapter, we will outline the descriptive metrics, framed by our initial objectives of exploring schedule and cost risk, with the following chapter taking a deeper dive into the trends and patterns of the helicopter portfolio's metrics that were of interest.

CHAPTER NINE

Initial Examination of Defined Metrics: Helicopter and Satellite Portfolios

The preceding chapter outlined how one constructs the foundation of a portfolio analysis. In this chapter, we explore in greater detail how one then assesses a set of metrics and visualizations through the lens of the portfolio analysis objectives. In our analysis, we focused primarily on cost and schedule performance indicators as the primary objective of our portfolio view of helicopter and satellite programs, and the following sections will outline observations from that perspective. In particular, this chapter will explore in greater depth the helicopter and satellite example portfolios (we discuss the "watch list" test case portfolio in Appendix B). We chose to discuss the portfolios together to highlight similarities and differences in the metrics and visualizations across the portfolio types. Overall, the following section tells the "what" of the portfolio analysis: What is the composition, or characteristics, and the performance indicators of the portfolio. Chapter Ten provides an example narrative to answer potential policymakers' follow-up questions as to the "why" and "how" the portfolios are presenting these results.

Descriptive Metrics

We started our analysis by looking at the descriptive metrics: latest milestone achieved, size of program, percentage of funds and time remaining, and percentage change in quantity, or churn. Because we were analyzing not just a snapshot in time but an 11-year time frame, we must also note how the composition of the portfolio changed over time as programs entered and left the portfolio.[1] The following discussion displays

[1] For our defined portfolio, programs "entered" or "left" the portfolio based on when they were submitting SARs. Therefore, a program enters the portfolio when it submits its first SAR and leaves the portfolio when it ceases SAR submissions, which can result when the program is 90 percent complete or has been cancelled. Portfolio composition also entails subcategories of the portfolio type in question. For example, with the helicopter portfolio, we may also note the mix of commodity type (force application versus logistics) within the overall portfolio.

our calculated metrics and the visualizations chosen to package this information for a potential policymaker.

Portfolio Composition and Latest Milestone Achieved

To review, Tables 9.1 and 9.2 show the composition, by program and most recent milestone achieved, of the helicopter and satellite portfolio in each year of our analysis.

Table 9.1
Helicopter Portfolio Composition Between 2002 and 2012

Program	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Army											
ARH				B	B	B	B				
CH-47F	B	B	C	C	C	C	C	C	C	C	C
Comanche	B	B									
UH-60M	B	B	B	C	C	C	C	C	C	C	C
AH-64D Longbow Apache[a]	C	C	C	C	C	C	C	C	C		
LUH					C	C	C	C	C	C	C
AH-64E Remanufacture[a]					B	B	B	B	C	C	C
AH-64E New Build[a]									C	C	C
CH-53K				B	B	B	B	B	B	B	B
Navy											
H-1 Upgrades	B	B	B	B	B	B	C	C	C	C	C
MH-60R	B	B	B	B	C	C	C	C	C	C	C
MH-60S	C	C	C	C	C	C	C	C	C	C	C
VH-71				B	B	B	B				

NOTES: A red B indicates that the program has passed Milestone B, and a blue C indicates that the program has passed Milestone C. A blank cell in the table suggests that the program has not started reporting SAR data, has been cancelled, or is no longer required to report SAR data. Our team chose these three portfolios both to test our methodology and present examples for future analysts to follow in their own portfolio analyses. Again, one may choose from a variety of acquisition characteristics to create a portfolio or a set of analogous portfolios for comparison.

[a] Three separate Apache acquisition programs are covered in this analysis. The AH-64D Longbow Apache was reported in the SARs from 1997 through 2010. It is referred to as "Longbow Apache" in subsequent figures in this analysis. The AH-64E Remanufacture started its SAR reporting in September 2006 under the name of "Longbow Apache–Block III (AB3)." It then was reported under the following names: Apache Block III (AB3), Apache Block IIIA (AB3A Remanufacture), and finally as AH-64E Apache Remanufacture (AH-64E Remanufacture) in December 2012. Even with the multiple name changes, it remained the same acquisition program. The AH-64E New Build started in 2010 and was formed based on the 2009 Nunn-McCurdy outcome of the AH-64E Remanufacture program. The first name for the New Build program was Apache Block IIIB New Build (AB3B New Build) in 2010 and was changed to AH-64E Apache New Build (AH-64E New Build) in 2012.

Table 9.2
Satellite Portfolio Composition Between 2002 and 2012

Program	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Air Force											
AEHF	B	B	B	B	B	B	B	B	B	B	B
GBS	B	B	B	B	B	B	B	B	B	B	B
GPS III							B	B	B	C	C
GPS OCX											B
NAVSTAR GPS	B	B	B	B	B	B	B	B	B	B	B
NPOESS	C	C	C	C	C	C	C	C	C	C	
SBIRS-High	B	B	B	B	B	B	B	B	B	B	B
SBSS						B	B	B	B		
TSAT			B								
WGS	B	B	B	B	B	B	B	B	B	B	B
Navy											
MUOS			B	B	C	C	C	C	C	C	C
NESP	C	C	C								

NOTES: A red B indicates that the program has passed Milestone B, and a blue C indicates that the program has passed Milestone C. A blank cell in the table suggests that the program has not started reporting SAR data, has been cancelled, or is no longer required to report SAR data.

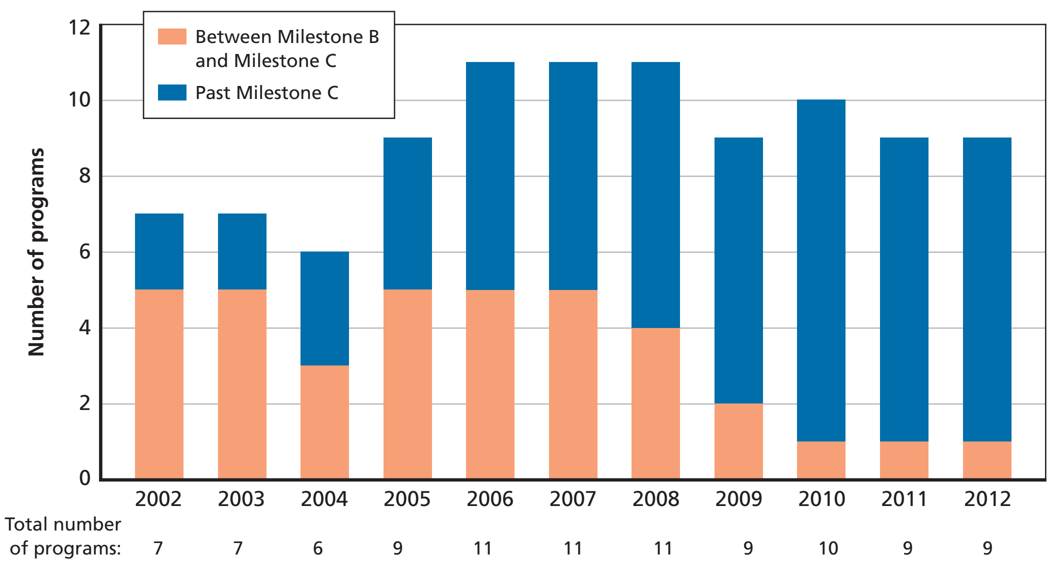
When outlining these results, a key observation is how the composition of both portfolios changes over time, with programs coming in and dropping out because of program completion or termination. This is especially important in the satellite portfolio, which experiences somewhat more flux in composition over the period under consideration. A second observation has to do with the maturity of the portfolios. The progression of Bs and Cs across the two tables suggests two very different trends. Whereas the number of Cs included in the helicopter portfolio increases over time, the number of Cs in the satellite portfolio remains largely the same. The trend in the helicopter portfolio clearly suggests the maturation of the portfolio. However, using the milestone metric as an indicator of maturity in the satellite program does not show this same trend. This may be partially because many satellite programs often never pass Milestone C due to the nature of satellite programs themselves.[2] Specifically, for satellite programs, the first

[2] See Department of Defense Instruction 5000.02, January 7, 2015: "Operation of the Defense Acquisition System." Some programs, notably spacecraft and ships, will not produce prototypes during EMD for use solely as test articles because of the very high cost of each article. In this case, the first articles produced will be tested and then fielded as operational assets. These programs may be tailored by measures such as combining the devel-

development unit is often considered the first operational unit as well. Because of the long build and test cycle for each satellite, cost and production rates do not ramp up as they do for other types of programs (LRIP and FRP have no meaning).[3]

Figures 9.1 and 9.2 show the importance of including key contextual information within a metric visualization. Figure 9.1 shows the same gradual maturation of programs within the portfolio and the shift from having a mix of programs at Milestones B and C toward a portfolio in which almost all programs have reached Milestone C. In Figure 9.2, we do not see a significant trend in terms of the distribution of programs by milestone passed for the satellite portfolio. The number of programs at Milestone C remains largely the same, although the programs represented do change over time. One reason for the lack of variation on this metric may be due to changes in portfolio composition. As new programs enter the portfolio, they have not

Figure 9.1
Helicopter Programs, by Milestone, 2002 Through 2012



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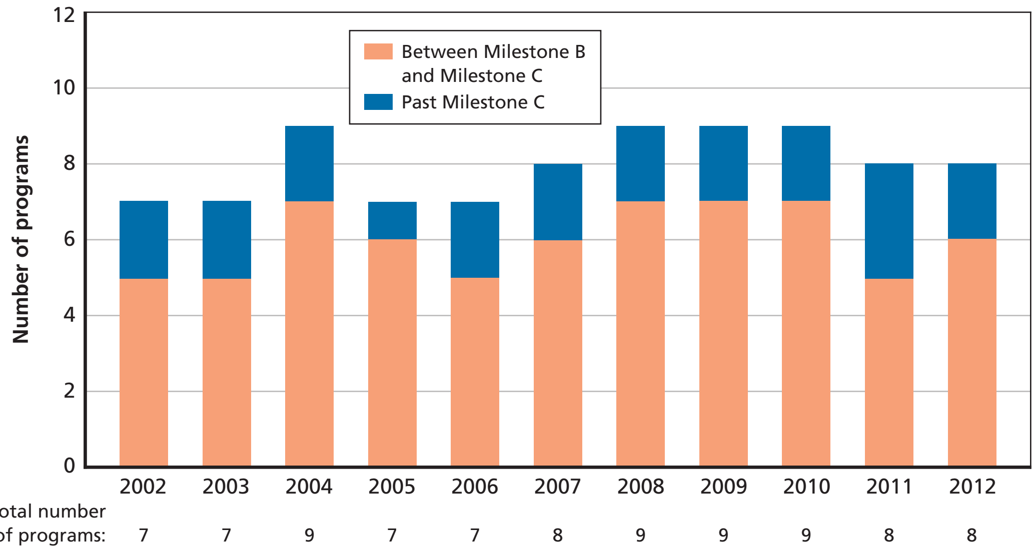
opment and initial production investment commitments. When this is the case, a combined Milestone B and C will be conducted. Additional decision points with appropriate criteria may also be established for subsequent low rate production commitments that occur prior to operational test and evaluation (OT&E) and a Full Rate Production Decision. For additional policy documentation on MDAs, see Under Secretary of Defense (Acquisition, Technology and Logistics), memorandum for the Secretary of the Air Force, Subj: Redelegation of Milestone Decision Authority (MDA), January 4, 2006; Acting Under Secretary of Defense (Acquisition, Technology and Logistics), memorandum for the [Acting] Secretary of Defense, Subj: Air Force Space Programs—Change in Milestone Decision Authority, March 25, 2005.

3 Because of data availability, the numbers differ for certain metrics. The number of programs included in each metric calculation is included in individual tables with each visualization.

Figure 9.2
Satellite Programs, by Milestone, 2002 Through 2012



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yet reached the appropriate milestone. Another may be the nature of satellite programs themselves and their different development trajectory, noted above.

Understanding the commodity types in which the programs in a given acquisition portfolio fall may also be important because it provides insight into the mission sets into which these acquisition programs fall. Figure 9.3 shows that the helicopter portfolio falls into two DAMIR categories, force application and logistics. Over time, the relative number of programs in the logistic category appears to increase as compared to the number of force application programs. Satellite programs also fall into two major DAMIR categories: battlespace awareness and net centric programs, as shown in Figure 9.4. Further consideration of how the distribution of commodity types in a given portfolio influences portfolio status and performance could be a valuable line of investigation during a complete portfolio analysis.

Program Size

The total program value metric is important because it gives analysts a sense of the average dollar value of programs in the portfolio as well as the range of program sizes within the portfolio (with program size measured using total cost in dollars). Our visualizations also provide insight into how the portfolio changes on this dimension over the assessment period. Figure 9.5 for the helicopter portfolio shows almost no change in total program value when considering the portfolio as a whole. Although the median does appear to move up slightly, this change is statistically significant only in the period 2008 to 2010. Another notable trend is the increase in the range of program

Figure 9.3
Helicopter Programs, by DAMIR Portfolio, 2002 Through 2012

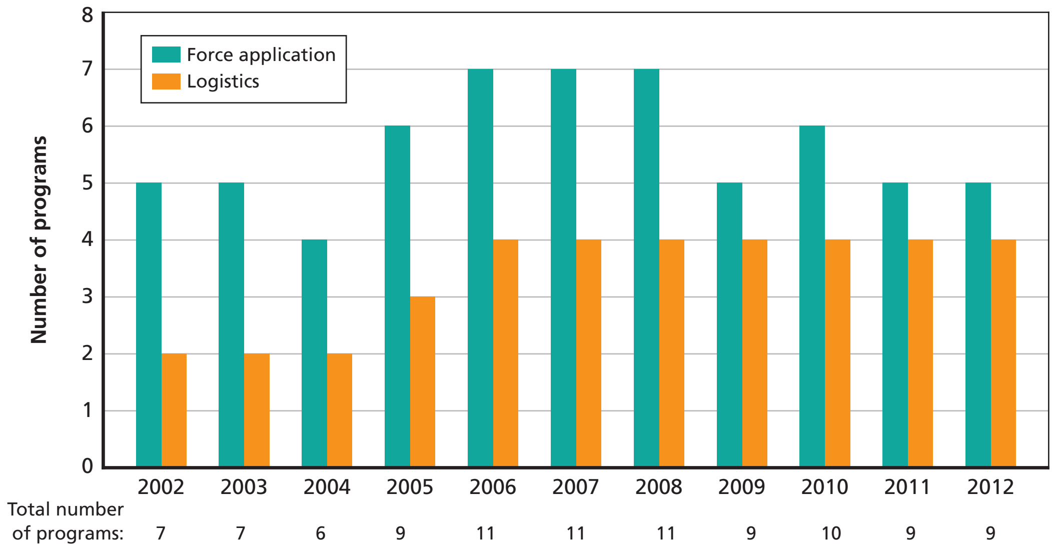

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Figure 9.4
Satellite Programs, by DAMIR Portfolio, 2002 Through 2012

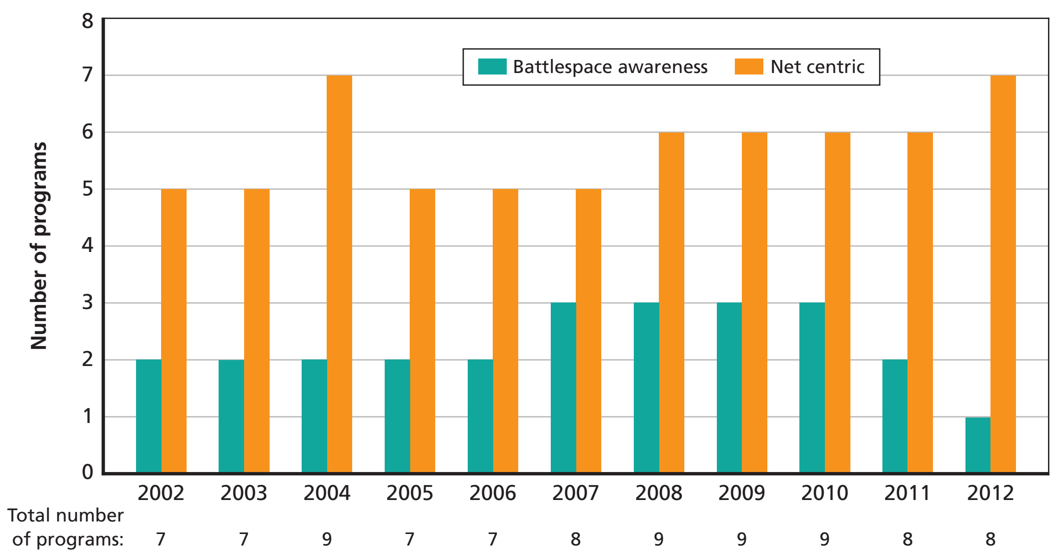

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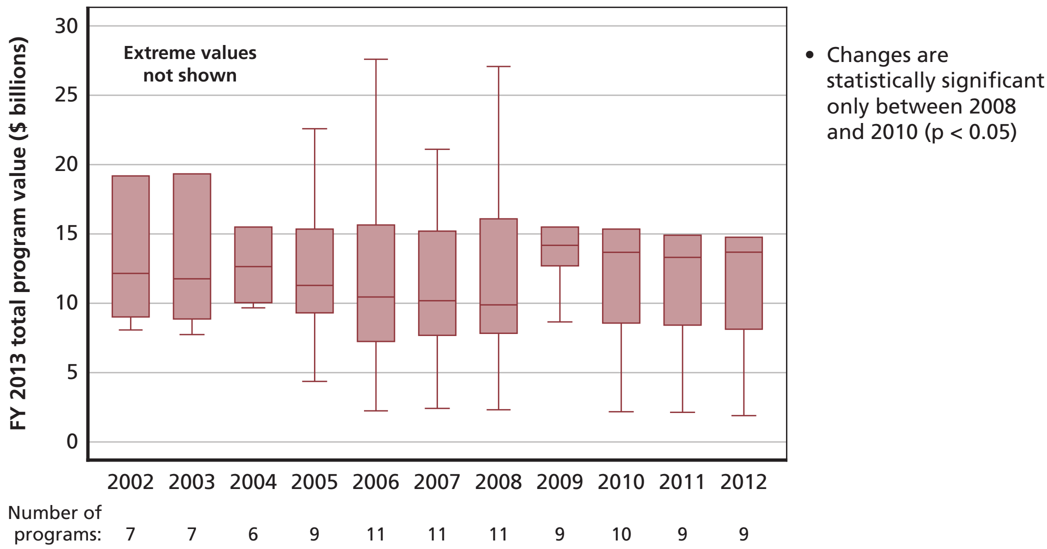
Figure 9.5
Total Average Program Value, Helicopter Portfolio, 2002 Through 2012



NOTE: The figure excludes Comanche in 2002 and 2003.
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values in 2006 through 2008. One can observe this increase by looking at the spread of the whiskers as well as the length of the interquartile range. Turning to the satellite portfolio, Figure 9.6, we see much less variation over time. There is a small, statistically significant increase in the median and an apparent increase in the range or spread of total cost values, but one that is much less dramatic than that observed for the helicopter portfolio. This greater stability in total program value in the satellite portfolio is somewhat surprising given the greater fluctuation in the portfolio's composition over time. It appears that even as the composition of the portfolio changes, the size of the programs included does not change substantially over time.

Percentage of Funds Remaining

Looking at the percentage of procurement and RDT&E funds remaining can be another way of thinking about program maturity, as a more mature program will have fewer funds remaining. Figure 9.7A and 9.7B show funds remaining for the helicopter portfolio. Looking first at procurement funds, two trends are worth discussing. First, there is a clear decline in the median over the period under consideration. This change is statistically significant in all years, and the results suggest a decrease of about 5 percent in funds remaining on average over the period. The second trend worth noting is the large increase in range, which occurs because although some programs do gradually spend their procurement budgets, other helicopter programs still have 100 percent of their procurement budgets remaining even in the final year of our analysis.

Figure 9.6
Total Average Program Value, Satellite Portfolio, 2002 Through 2012

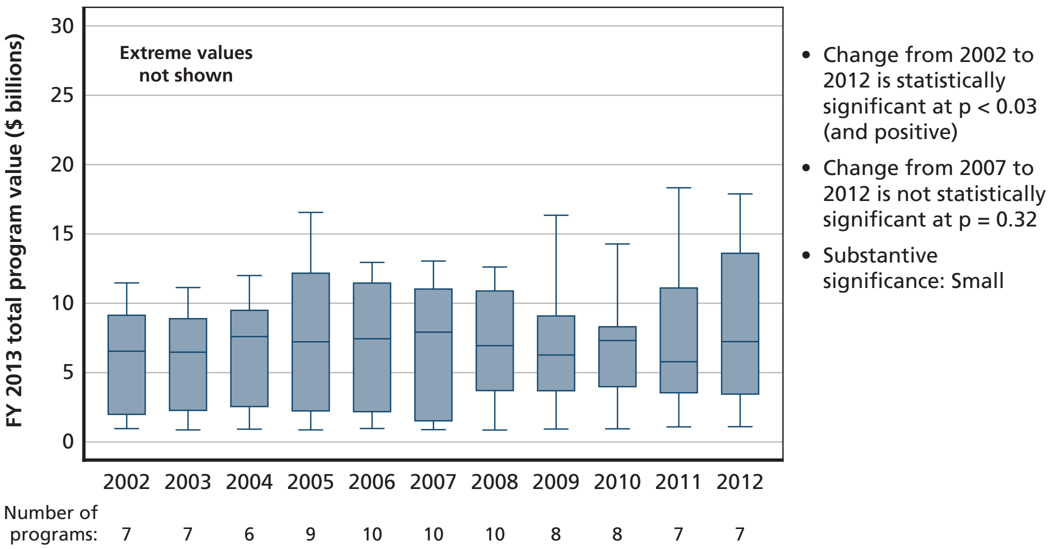

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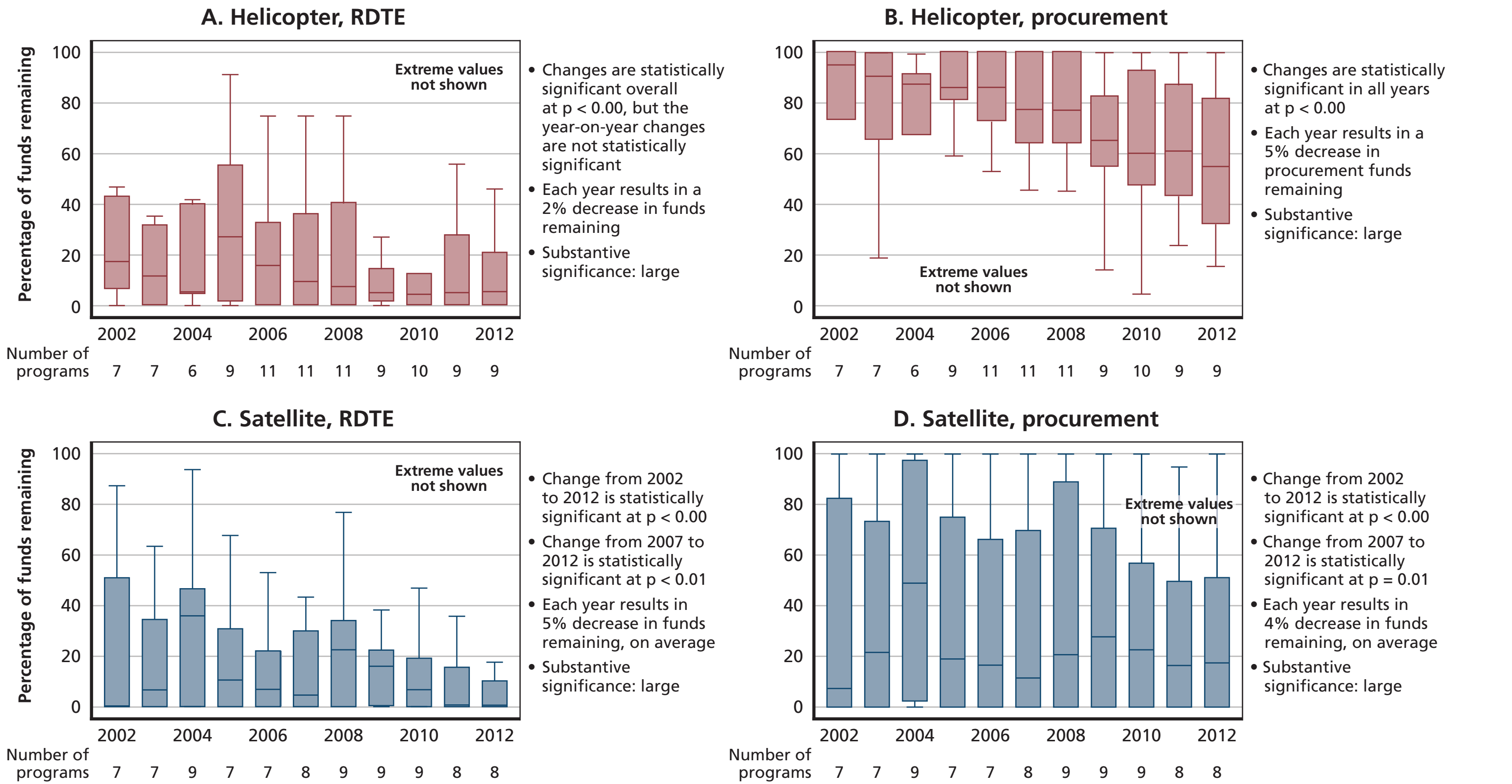
Figure 9.7A shows the change in RDT&E funds remaining over the same time period. Once again, we see a gradual decline in the median funds remaining, which is consistent with previous graphs that suggested a maturing helicopter portfolio. This decrease is once again statistically significant overall, although the year-on-year changes are not statistically significant. We can also see a sizeable decrease in the range until 2010, as most programs appear to converge toward having fully spent their RDT&E funds. Notably, the range increases again in 2011, reflecting an infusion of new RDT&E funds received by the AH-64E Remanufacture in 2010 (AH-64E is an outlier in 2010 as a result and is not shown in the figure). These new funds were intended to support additional improvement in the AH-64E's combat capability.

Figure 9.7C shows the percentage of RDT&E funds remaining for the satellite portfolio. The figure shows that over the period under consideration in this assessment, programs in the satellite portfolio have gradually spent their RDT&E funding. Little variation appears in the amount of this type of funding left by 2012. As noted elsewhere in the report, this is evidence that the portfolio is becoming more mature, with more programs entering the procurement phase. Figure 9.7D shows the percentage of procurement funds remaining for the satellite portfolio. We can see that although the statistical analysis suggests a decline in procurement dollars remaining on average over the period under consideration, the figure suggests a very different trend than that observed for the helicopter portfolio. For the satellite portfolio, the median seems to jump around a bit more, and the range spans from 0 to 100 percent funds remaining in all years. This partly reflects the greater flux (with programs more frequently enter-

Figure 9.7
Percentage of Funds Remaining, 2002 Through 2012



NOTES: Percentage of RDT&E remaining—helicopter portfolio programs omitted: Longbow Apache in 2002. Percentage of procurement funds remaining—helicopter portfolio programs omitted: CH-53K in 2008–2012, AH64E Remanufacture in 2010.

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ing and leaving the portfolio) observed in the satellite portfolio's composition: As new programs enter, they may not have spent procurement dollars yet. However, the different trend is also confirmatory evidence that the satellite and helicopter portfolios have some significant differences in overall status and likely risk as well.

Portfolio Churn: Quantity Changes

When assessing the effects of quantity change on portfolio status, we focused on churn, or the percentage of programs experiencing any quantity change in each year of our analysis. As noted above, changes in quantity may not indicate serious problems. Instead, a change in quantity (a decrease in particular) can be driven by a change in need for a weapons system. It could also be due to affordability within a given portfolio. Although not always indicative of a problem within the affected program, high levels of churn are sometimes associated with unit cost growth, schedule slippage, and other performance problems as they may significantly alter manufacturing schedules, leading to a less-than-optimal economic rate of production.[4] Looking at our churn visualizations in Figures 9.8 and 9.9, we can see that both the satellite and helicopter portfolios experienced varying amounts of churn in the years of our assessment. For the helicopter portfolio, quantity churn primarily occurs because of increases in quantity, with the highest amounts in the portfolio occurring between 2003–2004, 2005–2006, and 2008–2009. However, analysis of the year-on-year differences suggests that none of these changes are statistically significant. The same is true when we compare the churn in 2002 to that in 2007 and that in 2012. The lack of statistical significance does not mean that changes in quantity do not occur and are not important; it means, rather, that any observed changes in quantity are more or less random over time. It is worth noting that a good amount of the growth in quantity in the early years of our time period is due to high demand for helicopters within the Marine Corps and the Army because of operations in Iraq and Afghanistan. The decrease seen toward the end of the period may similarly reflect a drop off in demand as these operations draw to a close.

There seems to be even more churn for the satellite portfolio, on both the positive and negative sides, especially between 2006 and 2009. In this case, some of the year-on-year changes are statistically significant. Specifically the churn values measured between 2006–2007, 2007–2008, 2008–2009, and 2009–2010 are statistically significant compared to the period prior. In the 2006–2007 period, there are a greater number of quantity changes and specifically a greater number of positive quantity changes. In the 2007–2008 period, the trend is in the opposite direction, with a larger number of negative quantity changes. In the 2008–2009 period, there are several large positive quantity changes. Finally, in the 2009–2010 period, there is little change in

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4 For a further examination of this concept, see Congressional Budget Office, "Effects of Weapons Procurement Stretch-Outs on Costs and Schedules," November 1987.

Figure 9.8
Percentage Change in Current Estimate Quantity, Year by Year, Helicopter Portfolio, 2002 Through 2012

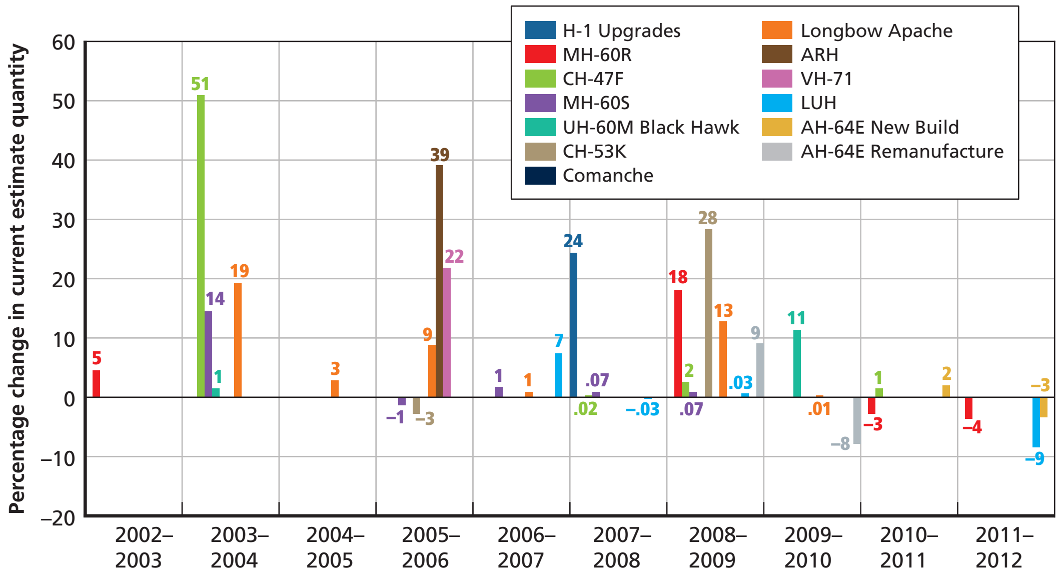

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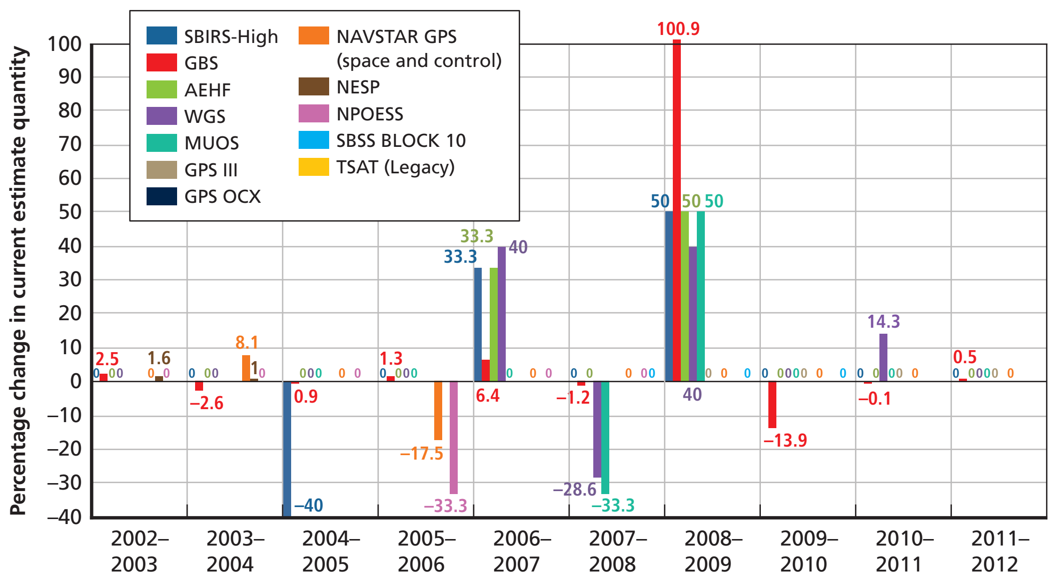
Figure 9.9
Percentage Change in Current Estimate Quantity, Year by Year, Satellite Portfolio, 2002 Through 2012



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either direction. Looking at five-year changes and the satellite portfolio, the change between 2002 and 2007 is statistically significant, but the change between 2002 and 2012 is not. This reflects the fact that there was significantly more churn in the middle years of our assessment than at the start or end of the period we consider in our analysis.

When studying portfolio churn, it is important to note that what constitutes a "high level" of churn can also vary across portfolio types because of program characteristics or simply the quantity levels involved. For example, both the ARH between 2005 and 2006 and WGS between 2006 and 2007 experienced a roughly 40 percent increase in quantity. However, ARH increased from 368 units to 512, whereas the WGS program increased from five to seven satellites. Satellite programs, with their typically low quantity levels, are more sensitive to quantity changes than are the higher-production helicopter programs. It is also worth noting that at least some of this churn may be driven by changes in the composition of the satellite and helicopter portfolio. Additional analysis in an assessment phase might explore what drove these changes and might attempt to make some diagnosis about what drove these changes in quantity and whether they signal performance problems or respond to some other type of external trigger or event.

Performance Metrics

With the descriptive metrics providing context, we then turned to the metrics that describe the cost and schedule performance outcomes of the portfolios. These performance metrics include the Nunn-McCurdy breaches representing unit cost growth and the APB breaches representing deviation from schedule, performance, and cost from the established APB. As stated above, although we wished to assess the amount of KPPs at or above threshold, data on KPPs were not consistently reported (in SARs and DAES) across services and programs.

Nunn-McCurdy and APB Breaches

Tables 9.3 through 9.5 show the number and types of Nunn-McCurdy and APB breaches within each portfolio over the period under consideration.[5] We have used tables to display this information because this seems to be the clearest way to represent portfolio performance using these metrics. In the tables, the numbers represent total breaches of each type within the portfolio in a given year. This means that if a program has three different types of breaches in one year, all three breaches will be recorded in the table. Table 9.3 provides insight into the difference between the satellite and helicopter portfolios in terms of Nunn-McCurdy breaches. The figure suggests somewhat

[5] Policy changes during our portfolio time frame changed the way that Nunn-McCurdy breaches were reported. The discussion on this issue can be found in Chapter Eleven.

Table 9.3
Significant and Critical Nunn-McCurdy Breaches Experienced, Helicopter and Satellite Portfolios, 2002 Through 2012

Year	Current				Original			
	APUC, critical	APUC, significant	PAUC, critical	PAUC, significant	APUC, critical	APUC, significant	PAUC, critical	PAUC, significant
2002	1		1					
2003								
2004		2		1				
2005	1		1		1	1	1	1
2006	1		1		1	1	1	1
2007	1	1 1	1	1	1	1	1	1
2008	2	1	1	1	2	1	1	1
2009	2 1		1	1	1	1 2		1
2010				1		1		1
2011						1		1
2012						1		1

Helicopter portfolio Satellite portfolio

more breaches in the satellite portfolio, although we did not consider the statistical significance of this difference.

Looking at Tables 9.4 and 9.5, we can consider APB breaches by number and type across the years of our analysis as they are reported in the SARs in the Threshold Breaches section. In general, an APB breach occurs when the program exceeds the targets for cost, schedule, and performance defined in the APB. There are a number of different types of APB breaches each with its own definition or criteria. We focus here on nine types of APB breaches:

- schedule: objective schedule value plus six months.
- performance: failure to achieve standards defined in APB document
- RDT&E cost: objective cost value plus 10 percent
- procurement cost: objective cost value plus 10 percent
- MILCON cost: objective cost value plus 10 percent
- acquisition operation and maintenance (O&M) cost: objective cost value plus 10 percent
- O&S cost: objective cost value plus 10 percent
- APUC: breach occurs when cumulative program cost increases ≥ 15 percent of the approved current baseline or 30 percent above the original baseline

Table 9.4
APB Breaches, by Program and Year, Helicopter Portfolio

Breach	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Schedule	CH-47F	MH-60R	H-1 Upgrades MH-60S	H-1 Upgrades	ARH H-1 Upgrades MH-60S VH-71	ARH MH-60S VH-71	ARH MH-60S VH-71	CH-53K MH-60S UH-60M	CH-53K UH-60M	CH-53K MH-60S	MH-60S AH-64E (New Build)
Performance	UH-60M	UH-60M	UH-60M	MH-60R UH-60M	MH-60R MH-60S	H-1 Upgrades MH-60R MH-60S	Longbow MH-60R MH-60S				
RDT&E cost	MH-60R		H-1 Upgrades MH-60S			ARH	ARH	CH-53K MH-60S	CH-53K	CH-53K	
Procurement	MH-60R		H-1 Upgrades Longbow MH-60S		ARH Longbow AH-64E Remanufacture	ARH Longbow	ARH Longbow	CH-53K Longbow MH-60R AH-64E Remanufacture	CH-53K Longbow UH-60M	CH-53K	
MILCON cost											
O&S cost	MH-60S	MH-60S	Longbow MH-60S	UH-60M	MH-60S	AH-64E Remanufacture MH-60S UH-60M	ARH UH-60M	LUH MH-60R MH-60S UH-60M	CH-53K LUH MH-60S UH-60M	CH-53K LUH MH-60S UH-60M	LUH MH-60S UH-60M
O&M cost											
PAUC	MH-60R		H-1 Upgrades			ARH		AH-64E Remanufacture			
APUC	MH-60R		H-1 Upgrades			ARH		AH-64E Remanufacture Longbow	Longbow		

NOTE: A change in the number and types of breaches between 2007 and 2012 is statistically significant, but the difference between 2002 and 2012 is not.

Table 9.5
APB Breaches, by Program and Year Experienced, Satellite Portfolio

Breach	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Schedule	NAV_GPS	NAV_GPS SBIRS	NAV_GPS SBIRS	GBS NAV_GPS NPOESS WGS	NPOESS	GBS NPOESS SBIRS	AEHF GBS NAV_GPS NPOESS SBIRS	AEHF GBS GPS III MUOS NAV_GPS NPOESS SBIRS	GBS MUOS NAV_GPS NPOESS SBIRS SBSS	GBS MUOS NAV_GPS NPOESS	AEHF GBS NAV_GPS WGS
Performance	AEHF NAV_GPS	AEHF NAV_GPS	NAV_GPS	NPOESS	GBS NPOESS		AEHF				
RDT&E cost		NPOESS	GBS NAV_GPS SBIRS	NAV_GPS NPOESS	NPOESS	NPOESS	AEHF NPOESS	AEHF MUOS SBIRS	MUOS SBIRS SBSS	MUOS	
Procurement cost			SBIRS	NPOESS WGS	NPOESS	AEHF NPOESS SBIRS	AEHF NPOESS SBIRS	AEHF GBS WGS SBIRS	GBS SBIRS	AEHF GBS SBIRS	GBS
MILCON cost											
O&S cost		NPOESS		SBIRS	SBIRS	SBIRS	SBIRS	SBIRS	WGS SBIRS	AEHF	WGS
O&M cost											
PAUC			SBIRS	NPOESS	GBS NPOESS	NPOESS	AEHF NPOESS	WGS	NPOESS SBSS	WGS	
APUC			SBIRS	NPOESS WGS	NPOESS	AEHF NPOESS	AEHF NPOESS	AEHF WGS			

NOTES: A change in the number and types of breaches between 2007 and 2012 is not statistically significant. A change between 2002 and 2012 is also not statistically significant.

- PAUC: breach occurs when cumulative program cost increases ≥ 15 percent of the approved current baseline or 30 percent above the original baseline.[6]

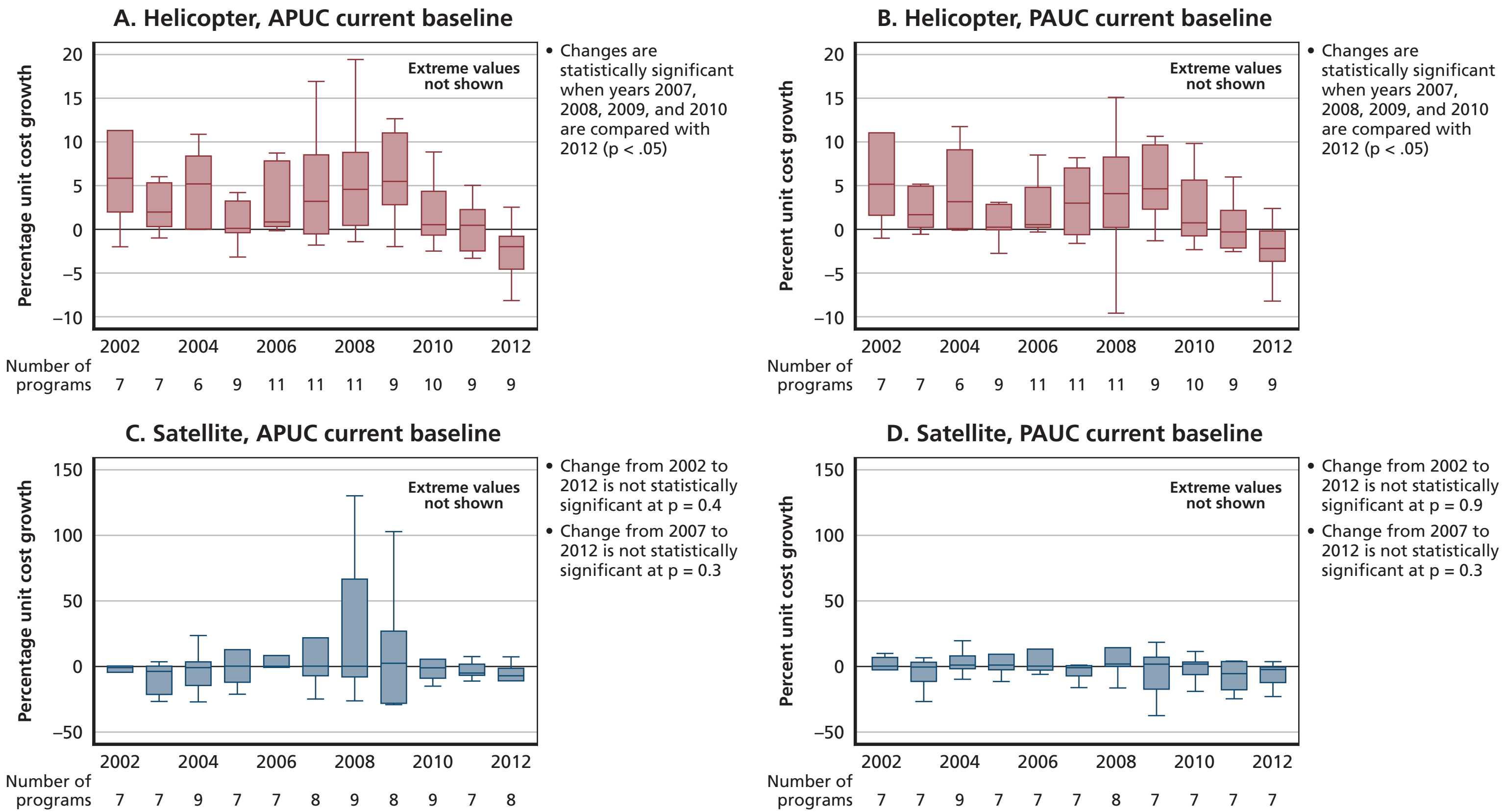
We can compare the number and types of APB breaches not only across portfolios but also over time to explore whether the number and types of breaches in 2002 are the same or different from those in other years, such as 2007 and 2012. When we conduct this analysis for the helicopter portfolio, we find that the difference is statistically significant when we compare the number of breaches in 2007 and 2012 (and suggests an improvement), but it is not statistically significant when we compare the number of breaches in 2002 and 2012. Neither the 2002 to 2012 nor the 2007 to 2012 difference is statistically significant for the satellite portfolio, however. Tables 9.4 and 9.5 also show the specific programs experiencing a breach in each year of the analysis. These tables are useful for analysts interested in knowing not only how many total breaches occurred (across all programs) but also which specific programs appear to drive these breaches.

Unit Cost Growth

For unit cost growth—a metric of high importance to policymakers and analysts—we considered a number of different visualizations. First, we looked at box-and-whisker plots, the interpretation of which was addressed in Chapter Eight. It is worth noting that for these graphs, although all programs were included in the data analysis, we have excluded outlier data points from the graph (the list of programs with data points not included is at the bottom of each figure). These outliers were included in the graph for presentational purposes only. Outliers are excluded because they lie so far outside the box-and-whisker part of the graph that they distort the graph, making it difficult to observe year-on-year changes. If desired, an analyst could make a different presentational decision. Figures 9.10A and 9.10B show these plots for the PAUC and APUC for the helicopter portfolio using the current baseline (and without the extreme values shown). Several trends are worth noting. One is the general decline in the median for both the PAUC and the APUC, particularly in the second half of the period under review, after about 2007. However, it is important to note that this trend reaches statistical significance for both the PAUC and APUC only when the years 2007, 2008, 2009, and 2010 are compared with 2012. Also, percentage unit cost growth in 2008 and 2009 was statistically different and higher than cost growth in other years. It is these statistically significant changes that we should be most interested in when conducting the portfolio assessment because they indicate a significant trend shift, possibly indicative of a change in overall performance. Observing increases and decreases in the median percentage unit cost growth is also valuable, but from the perspective of any acquisition executive, longer-term and meaningful trends are the more important

[6] Department of Defense Instruction 5000.02, 2015, pp. 59–61.

Figure 9.10
Percentage Unit Cost Growth, APUC and PAUC Current Baseline, 2002 Through 2012



NOTES: PAUC and APUC growth, helicopter portfolio: Comanche excluded 2002, VH-71 excluded 2005–2008 PAUC, satellite: NESP 200–2004 APUC satellite, NESP 2002, 2004; NPOESS 2005–2008, AEHF 2010, SBIRS-High 2012.

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measures of performance. Even then, the substantive size of the observed effect size is only moderate. We can also consider the change in the range or the spread of the data. After increasing somewhat between 2002 and 2008, the range also appears to shrink, likely because several programs with higher cost growth are terminated or rebaselined. To understand the factors driving these trends, we would need to separately consider the unit cost growth in individual programs within the portfolio. We look into some of these trends in Chapter Five, although a comprehensive assessment is still outside the scope of this report.

For the satellite portfolio, we use the same unit cost visualizations to present our metrics of portfolio status. Figure 9.10C and 9.10D show the box-and-whisker plots for the satellite portfolio focused on the APUC and PAUC metrics. First, it is worth noting that none of the year-to-year changes in the PAUC and APUC of the portfolio are statistically significant. This means that overall, portfolio status on unit cost does not seem to change all that much. The PAUC graph illustrates this lack of change. The median appears to hover around zero and although the range of the data does vary somewhat over time, there does not appear to be a consistent pattern. However, the APUC graph does show some more significant changes. The median once again appears to be fairly steady, at or around zero. However, there is more fluctuation in the range, which goes from very narrow in 2002 to very wide in 2008 and 2009. This change appears to be driven by a few poor performers in 2008 and 2009, namely, the AEHF, NPOESS, and WGS programs, which have high unit cost growth in these years. It is important to note that both the AEHF and NPOESS were later cancelled and so drop out of our portfolio. Partly for this reason, the cost-growth range returns to its original spread by the end of the assessment period in 2013. In this case, the cancellation of the programs improves the overall performance of the portfolio.

Figures 9.11 and 9.12 show a different way to assess the unit cost growth performance at the portfolio level. Although the bars for each program provide insight into the performance of specific programs in each of the years shown, the overall graph shows a snapshot of the unit cost growth distribution across all programs in the portfolio at a single point in time. Figures 9.11 and 9.12 allow us to look at the distribution of cost growth by program. We focus here on the changes between 2002 and 2012 (Figure 9.11A) and 2007 and 2012 (Figure 9.11B), although similar comparisons could be completed for all years. These graphs can be used to identify some of the extreme values (on the positive and negative sides) and to see how programs perform relative to others within the portfolio. For example, Figure 9.11A highlights the high cost growth experienced by the RAH-66 Comanche in 2002 and the negative cost growth experienced by the UH-60 Black Hawk program in 2012. Figure 9.11B similarly highlights the apparently strong unit cost performance of the VH-71 Presidential Helicopter and the sizeable cost growth experienced by the Armed Reconnaissance Helicopter (ARH) in 2007. However, when considering the 2012 performance of the VH-71, it is important to note that 2012 SAR was later judged to be inaccurate. In reality, the program

Figure 9.11
Percentage Unit Cost Growth APUC and PAUC Current Baseline, Helicopter Portfolio, 2002, 2007, and 2012

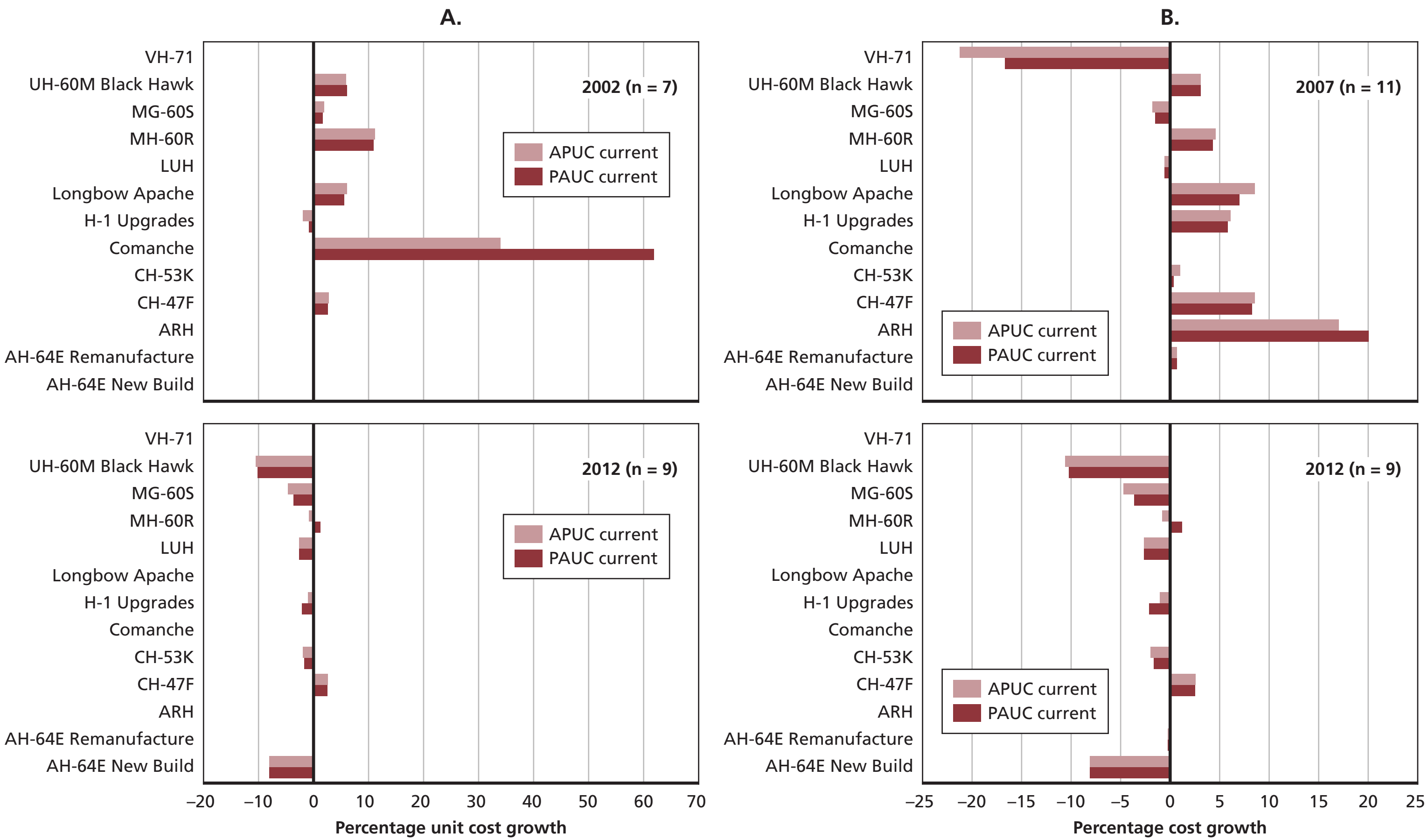

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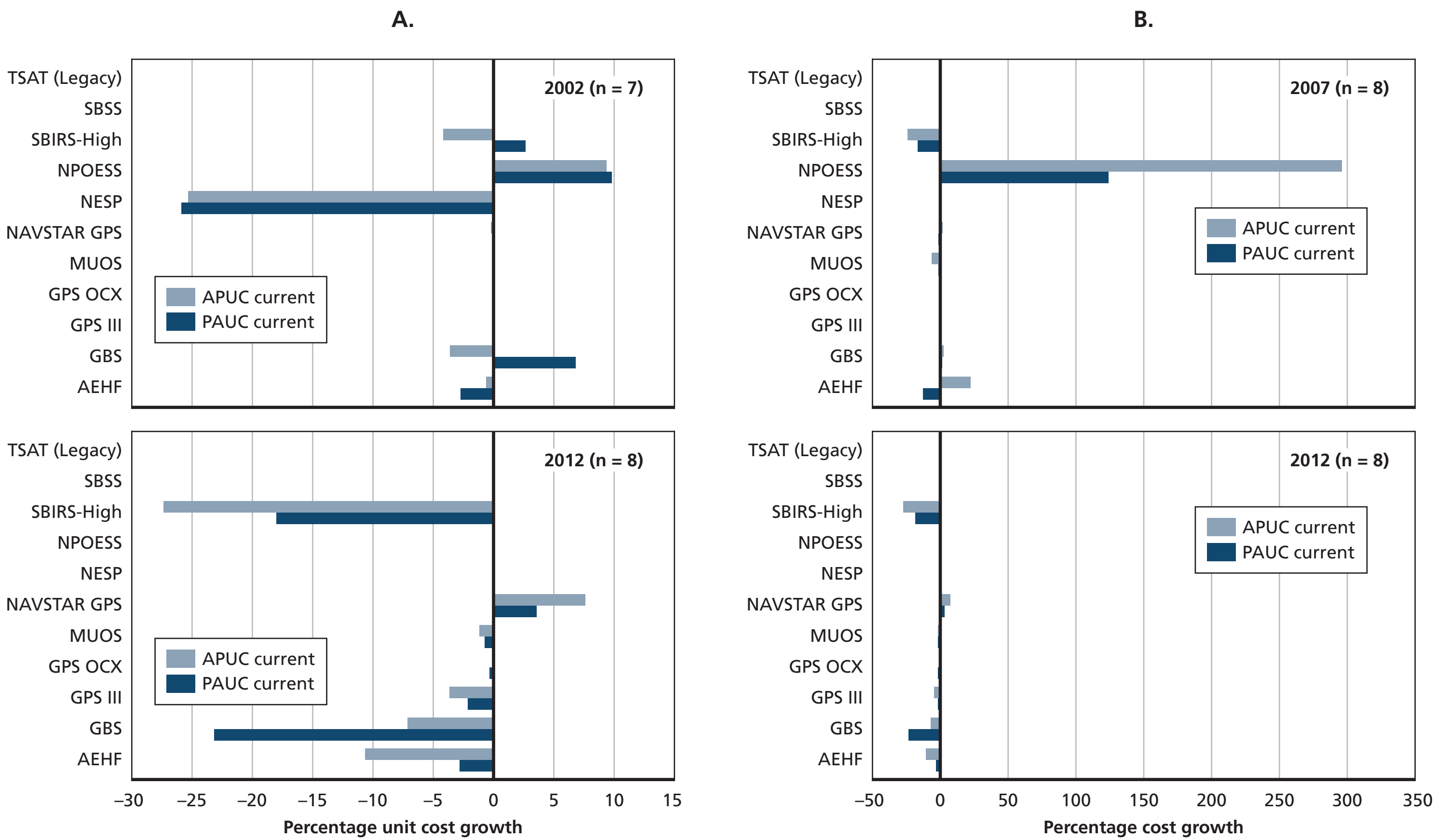
Figure 9.12
Percent Unit Cost Growth, APUC and PAUC Current Baseline, Satellite Portfolio, 2002, 2007, and 2012



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was performing poorly and had serious problems that were at odds with the trends suggested by the graphs and metrics in this report and the data that underlie them. This suggests that the data being reported by program directors warrants additional scrutiny and highlights an important point: Our ability to analyze and assess program and portfolio performance is only as good as the data provided. If data are false or inaccurate, then the metrics and visualizations produced based on these data will be similarly skewed. Analysts conducting portfolio assessments should, in addition to calculating metrics, investigate the programs being studied in additional detail to understand program history and other similar factors.

A final notable change visible in the 2012 graph is the negative cost growth experienced by the AH-64E New Build in 2012. This program was not active in either 2002 or 2007. To complete a comprehensive analysis of unit cost growth, an analyst would need to consider similar charts for all years. Looking only at 2002, 2007, and 2012 disguises programs with high unit cost growth and PAUC or APUC breaches in other years. For example, the AH-64E Remanufacture has an APUC and PAUC breach in 2009 that is missed by considering only the three years shown in Figure 9.11.

Several programs stand out for the satellite portfolio (Figures 9.12A and 9.12B). In 2002, the NPOESS and GBS programs show sizeable amounts of unit cost growth, but the NESP program has a negative change in unit cost. In 2012, the GBS program has a significant negative change in unit cost, suggesting that the program may have been able to turn things around. Also showing negative unit cost growth are the AEHF and SBIRS-High programs. In 2007, all trends are dwarfed by the large increase in unit cost experienced by the NPOESS program.

The final unit cost visualization that we consider in our analysis is the heat map (Figure 9.13). The different colors in the heat map represent program performance on unit cost in each year of the analysis. As noted above, by reading down a column, an analyst can get a sense of the portfolio's unit cost performance in any given year. Reading across any given row offers insight into the performance on unit cost growth of any single program over the full period under consideration. Viewing the map as a whole, then, also tells the analyst about trends in unit cost performance over time. Looking at this trend for the helicopter portfolio suggests a gradual trend toward green or a gradual improvement of the portfolio on this metric. However, this chart does not consider the statistical significance of any change. The heat maps can also help to identify patterns in the data. For example, for both the ARH and the Longbow Apache, we observe that APUC cost growth is at its highest right before the program is cancelled. However, the H-1 Upgrades program has a similar pattern between 2006 and 2008 but manages to improve performance. In our analysis of the helicopter portfolio in Chapter Ten, we investigate the program differences that allowed the H-1 Upgrades program to perform better after the 2006 to 2008 downturn and to continue, whereas other programs suffering similar downturns were later cancelled. The AH-64E Remanufacture similarly has poor unit cost growth performance in its early years, but seems to improve

Figure 9.13
"Heat Map" of Unit Cost Growth Performance, Helicopter Portfolio, 2002 Through 2012

NOTES: These charts show the percentage unit cost growth compared to the previous year. The color shown in 2002 reflects the change compared to 2001 for programs that were active in this year.

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markedly starting in 2010 following a 2009 breach in PAUC and APUC. Notably, however, this breach was due to an Army decision on accounting and cost-reporting rather than a change in the program's performance.[7] The improvement in unit cost growth followed a 2010 rebaseline.

Finally, looking at the heat map of the satellite portfolio (Figure 9.14), we once again can observe changes in the portfolio's performance on this dimension at a single moment as well as over time and can also assess changes in the status of individual programs. For the satellite portfolio, we can see a clear trend of increasing green and decreasing red, suggesting a gradual improvement in the portfolio's APUC performance. However, there appears to be less red at the start of our analysis in 2002 than was the case for the helicopter portfolio. At the same time, there are also satellite programs with significant periods of red, suggesting high levels of unit cost growth in these years. For example, looking at the APUC graph, the AEHF program has high unit cost for a significant portion of the assessment period, as does the NPOESS program and the NAVSTAR GPS program. However, although the NPOESS program is cancelled by 2009, the AEHF program appears to turn its performance around starting in 2011. Additional analysis in an assessment phase might highlight differences between the two programs that can explain these different outcomes. Looking at the PAUC, we again see a trend to green, as well as more limited pockets of red, or poor cost-growth performance. The NPOESS and SBSS Block 20 program appear to have the most substantial and sustained unit cost growth. However, there are several programs with short periods of high unit cost growth, including WGS, MUOS, AEHF, and GBS. Each of these programs has been able to overcome this cost growth issue, however. Additional analysis could explore how and why some programs are able to overcome cost growth problems, but others are not.

Multimetric Charts

We also considered two multimetric charts (charts that consider more than one metric at a time) for each portfolio. First, we looked at bubble charts, which consider both unit cost and program size. Second, we looked at radar charts, which provide insight into the aggregate performance of a program across several different metrics.

Figure 9.15 shows the bubble chart for the helicopter portfolio and compares across three years, 2002, 2007, and 2012. As noted in Chapter Eight, an analyst would be most concerned about programs in the upper right quadrant of the graph, particularly when these programs are large (represented by large bubbles). The best performers will be located in the lower left quadrant of the graph. For example, in 2007, the ARH program warrants some concern because it is high in the upper right quadrant whereas

7 Department of Defense, *AH-64E Remanufacture,* Selected Acquisition Report, 2013a.

Figure 9.14
"Heat Map" of Unit Cost Growth Performance, Satellite Portfolio, 2002 Through 2012

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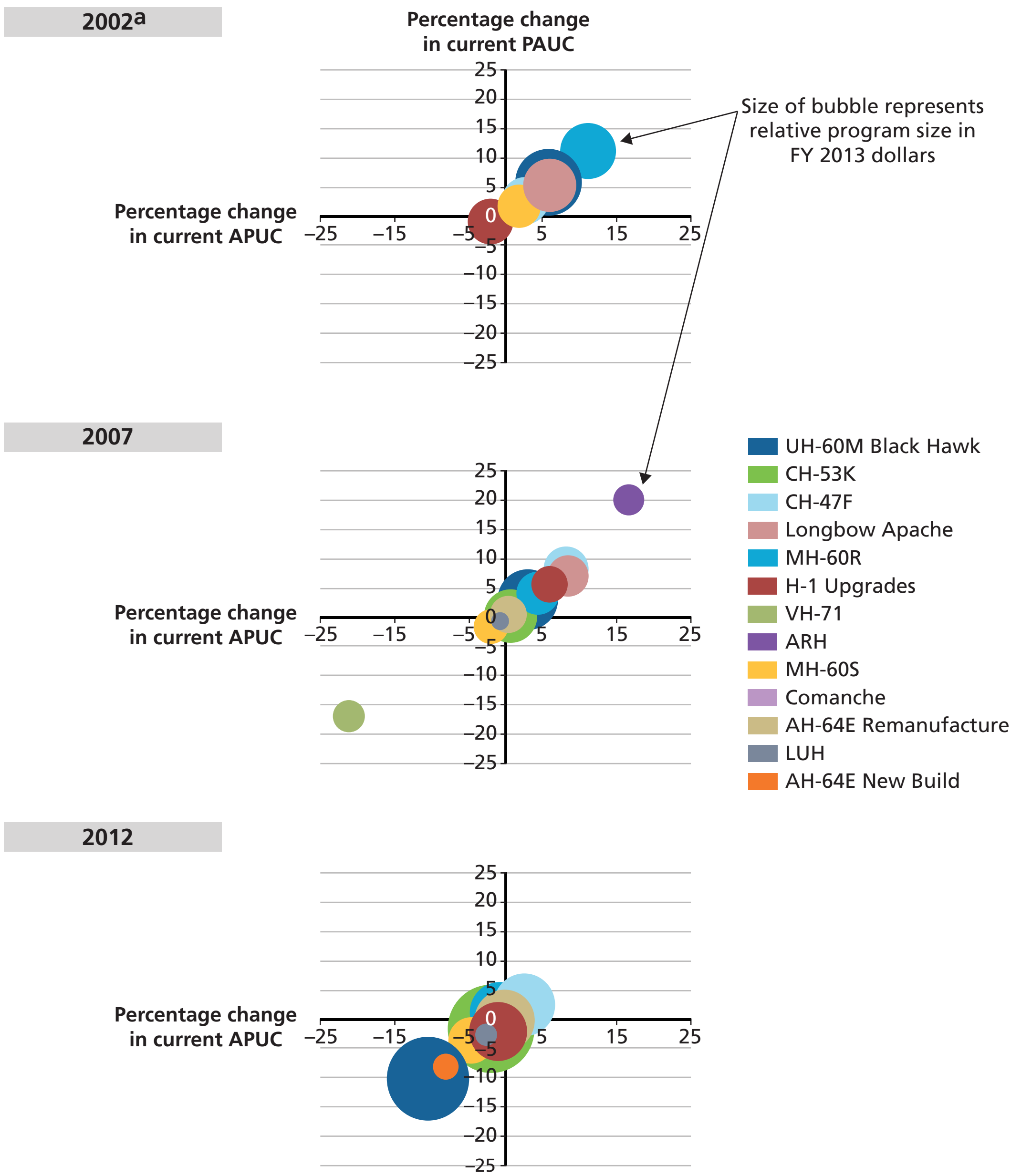
Figure 9.15
Unit Cost Growth and Program Size, Helicopter Portfolio, 2002, 2007, and 2012



[a]2002 does not include Comanche with cost growth in excess of 30 percent APUC and 60 percent PAUC.

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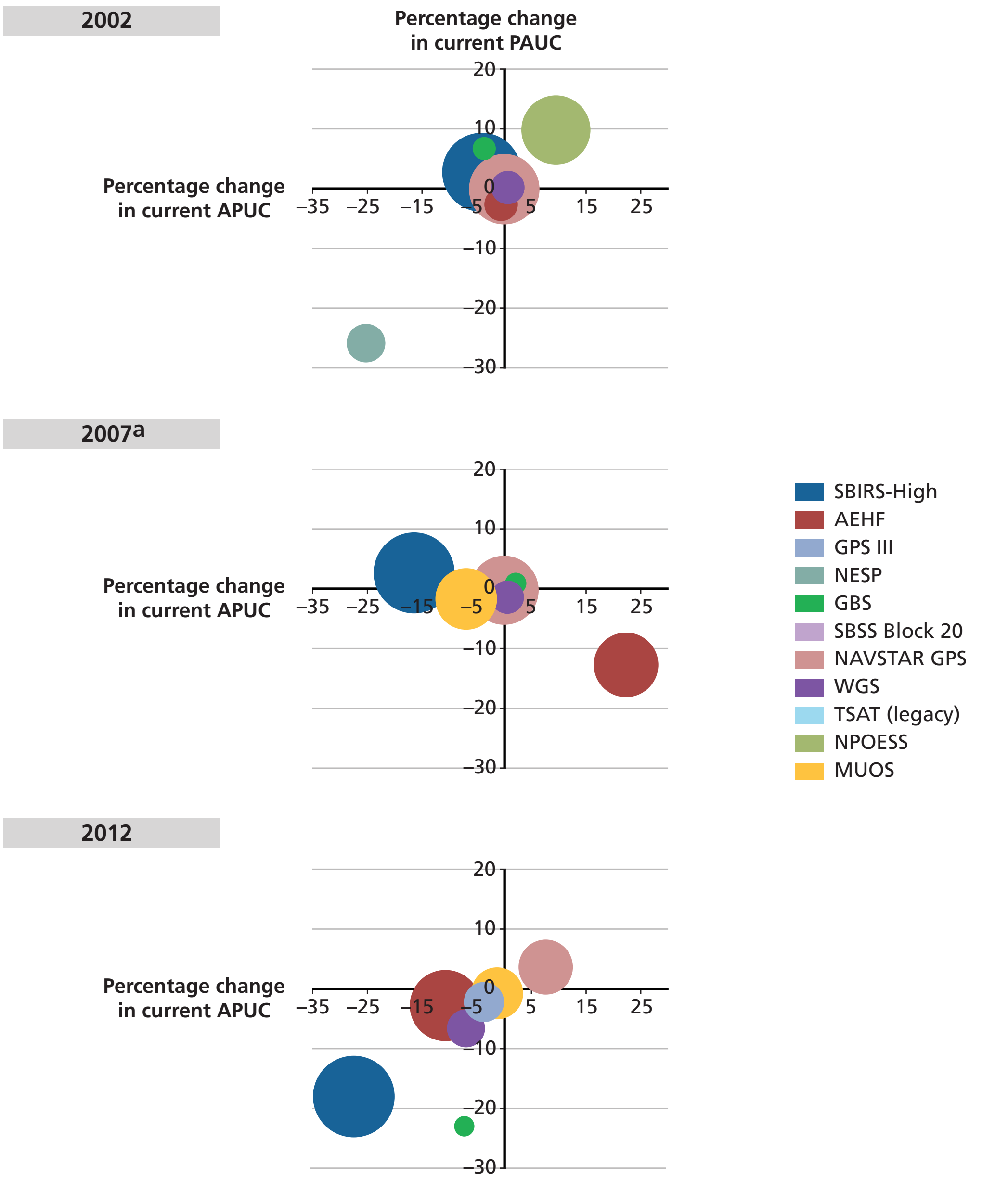
the VH-71 appears to show strong performance in the lower left (but as described above, this apparent performance is based on poor quality data and is misleading).

Also performing well in 2012 is the AH-64E New Build. An analyst would want to pay special attention to the UH-60M Black Hawk, MH-60R, and CH-53K as large programs whose performance might be more meaningful for an analyst than the performance of an average program. In 2012, for instance, the fact that the Black Hawk program has moved into the lower left quadrant is a positive one for the performance of the overall portfolio.

Figure 9.16 shows the same type of plot for the satellite portfolio in the same three years, 2002, 2007, and 2012. Already in 2002, the performance of the NPOESS program appears somewhat problematic, especially given the fact that it is a relatively sizable program. The SBIRS-High program also shows some cost growth as does the GBS program, although this program's small size decreases the level of concern about its effect on portfolio performance. In 2007, both the SBIRS-High and AEHF show substantial cost growth (although in each case, the programs show only one type of cost growth and so appear in the upper left and lower right quadrants). An analyst should be concerned about both programs given their substantial size. Concern about the MUOS program might also be warranted. Finally in 2012, the picture seems to have changed somewhat. Now, the SBIRS-High program is a sizeable, strong performer with negative unit cost growth. The AEHF program also shows some improvement, important again because of the program's size. The GBS program is another strong performer in this case with negative percentage change in APUC and PAUC (although it is small). However, one program still warrants some additional concern, namely, the NAVSTAR GPS program.

The final visualization we used in our analysis combines six different metrics into a radar plot, also described in Chapter Eight. Each of six vertices of the figure represents a different metric, and the shape made by connecting a portfolio's status on each of these six metrics creates a shape that provides an aggregate view of the portfolio in any given year. The six vertices represent the percentage of programs with a 5 percent or more unit cost growth (PAUC and APUC), the percentage of programs with an APB breach, the percentage of programs with a Nunn-McCurdy breach, the percentage of programs with any quantity change compared to the prior year, and the percentage of programs pre–Milestone C. Because one of the vertices compares one year of the portfolio with a prior year (quantity), we can present only 10 charts for our 11 years of data (no graph is shown for 2002). In general, a smaller shape represents better performance overall—lower unit cost growth, fewer changes in quantity, and fewer breaches. We can compare the portfolio's status over time by comparing the size of these shapes in each year of assessment. We present two ways of doing this in Figure 9.17, which shows the radar plots for the helicopter portfolio in each of the ten years of our assessment. Although the size of the shape in the radar plot increases initially though about 2009, it appears to shrink gradually after 2010. Also notable from this figure is the

Figure 9.16
Unit Cost Growth and Program Size, Satellite Portfolio, 2002, 2007, and 2012



[a]2007 does not include NPOESS with cost growth in excess of 295 percent APUC and 123 percent PAUC.

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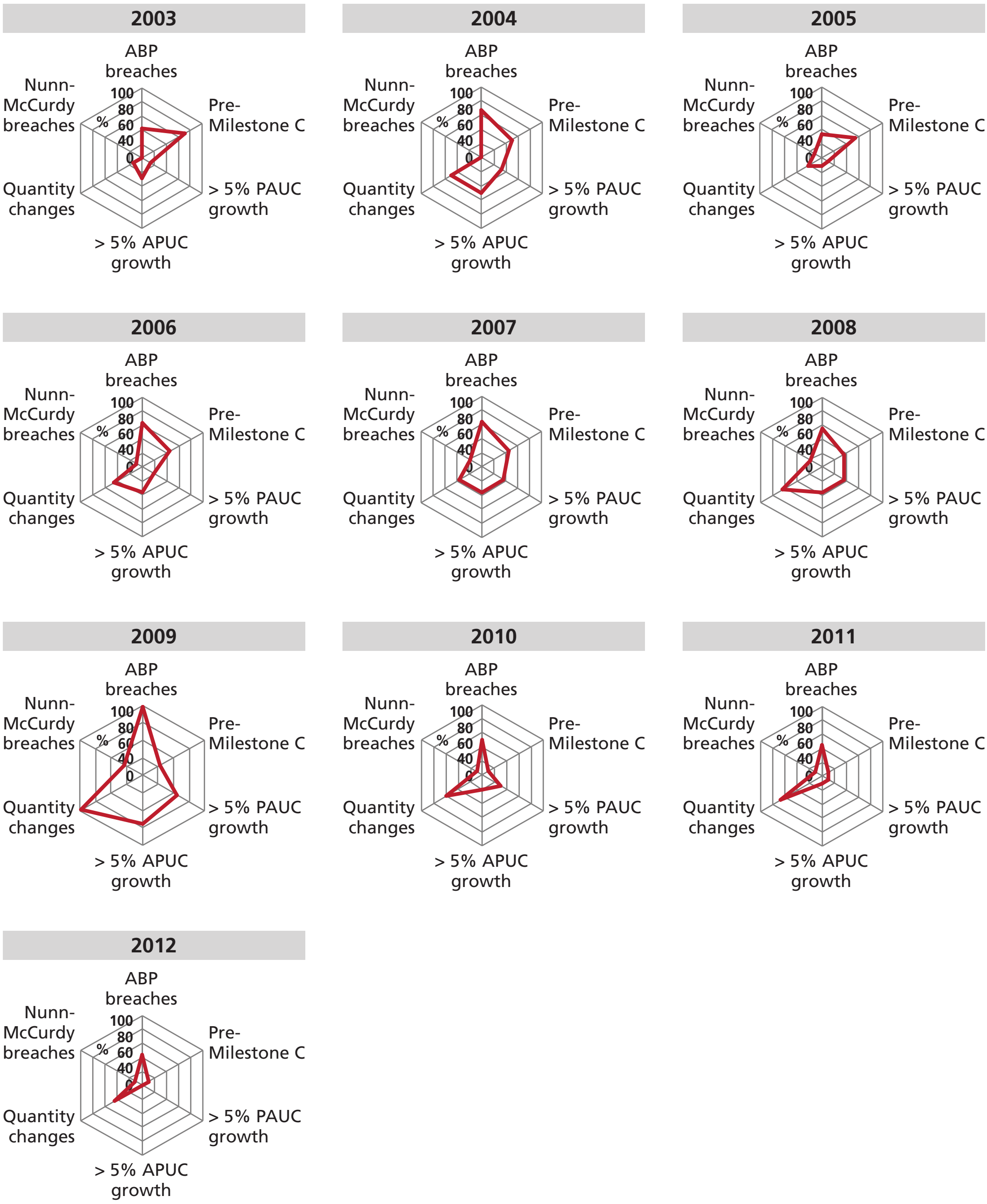
Figure 9.17
Aggregate Portfolio Performance, Helicopter Portfolio, 2002 Through 2012



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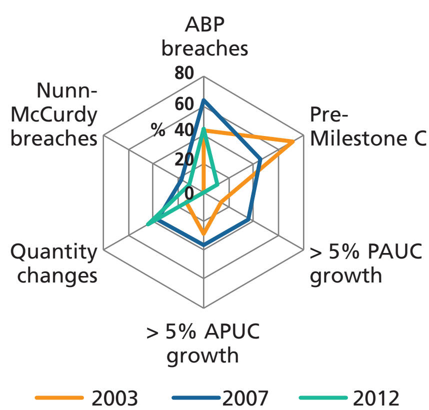
fact that there appears to be an increase in the percentage of programs experiencing quantity changes in 2011 and 2012. However, as noted elsewhere, having a change in quantity procured is not necessarily a sign of poor program or portfolio performance. Figure 9.18 shows the radar plots for 2003, 2007, and 2012 on a single chart and presents a similar view of the evolution of portfolio performance over time. Although the shape for 2007 is larger than that for 2003, the shape for 2012 is considerably smaller than the other two. This would be consistent with the story told by many of the individual metrics: There is an apparent improvement in the portfolio's performance after about 2008. However, our analysis thus far has not looked into why we see this change, what factors might be driving it, or whether it represents a true improvement of the entire portfolio or simply a change in one or two programs.

Figures 9.19 and 9.20 show the radar charts for the satellite portfolio, first for all ten years and then for 2003, 2007, and 2012 on a single graph. The ten-year comparison shows a shape that appears to change and increase in size over the period 2003 to 2010 before shrinking in 2011 and 2012. It is interesting that the changes in the radar charts for the satellite portfolio are changes not only in size but also in shape. This suggests that the status of the portfolio on the six different metrics changed in different ways in the ten years of our analysis. This is consistent with our general observation that the composition of the satellite portfolio appears to change more often over time. Future assessments can consider the reasons for the changing shapes of these radar plots in more detail. Finally, Figure 9.20 compares shapes for years 2003, 2007, and 2012. Although the shape for 2007 is somewhat larger than that for 2003 and 2012, the shapes for 2003 and 2012 are more similar. This pattern is similar to that observed for other metrics, namely, a satellite portfolio that had several years of declining per-

Figure 9.18
Aggregate Portfolio Performance, Helicopter Portfolio, 2003, 2007, and 2012



Number of programs	
2002	7
2003	7
2004	6
2005	9
2006	11
2007	11
2008	11
2009	9
2010	10
2011	9
2012	9

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Figure 9.19
Aggregate Portfolio Performance, Satellite Portfolio, 2002 Through 2012

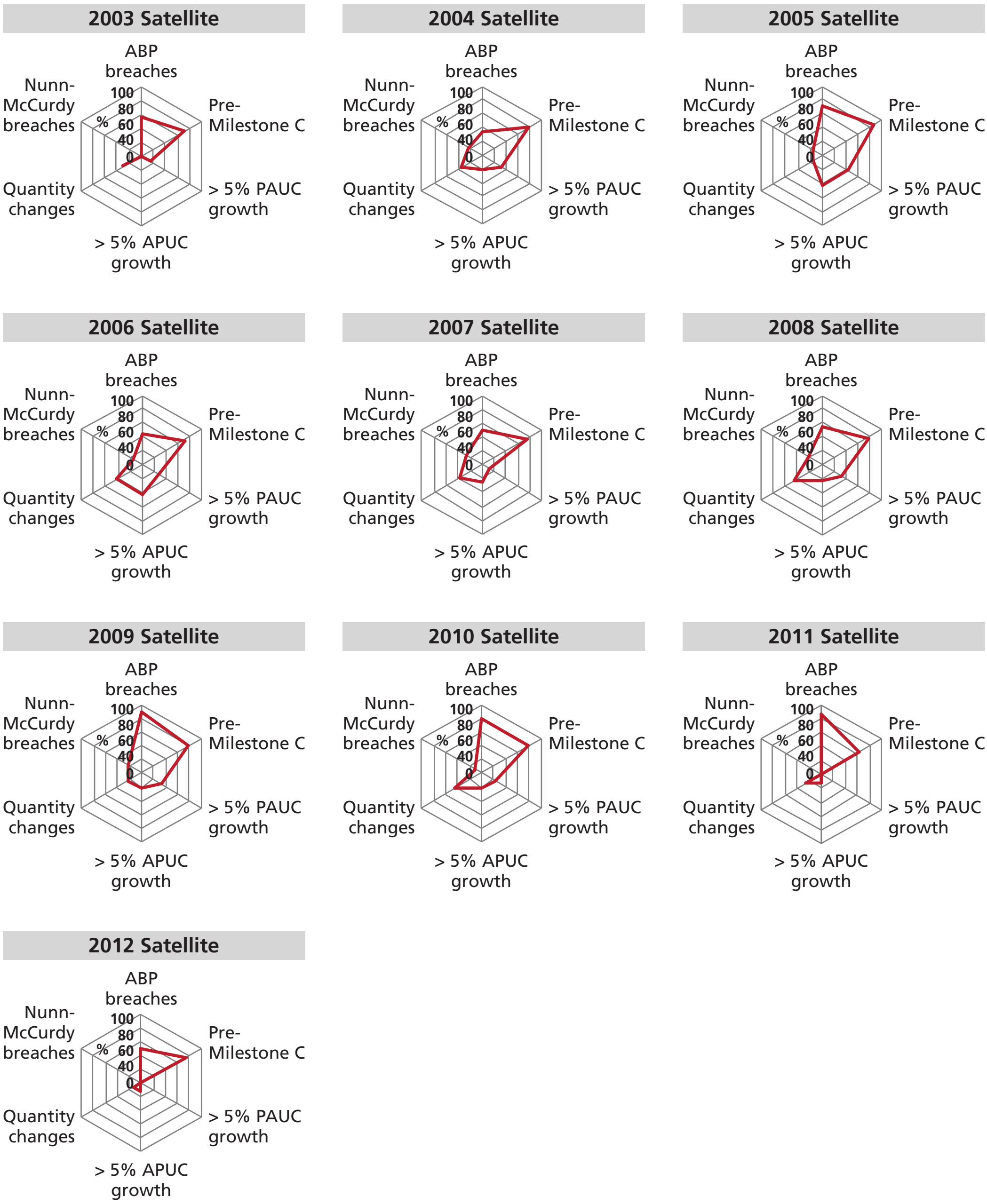

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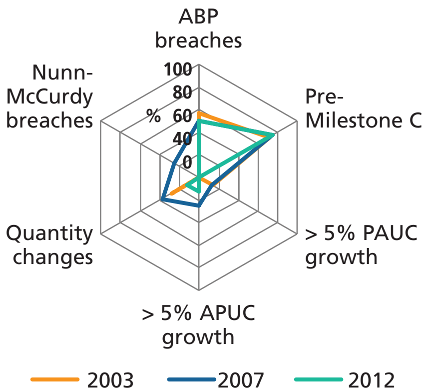
Figure 9.20
Aggregate Portfolio Performance, Satellite Portfolio, 2003, 2007, and 2012



Number of programs	
2002	7
2003	7
2004	9
2005	7
2006	7
2007	8
2008	9
2009	9
2010	9
2011	8
2012	8

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formance between 2002 and 2012 but that improved somewhat in recent years. A follow-on assessment of the portfolio could explore the drivers of this pattern, including specific programs responsible for the overall trend and external triggers or events that might explain the observed changes over time.

Chapter Summary

This section applied our methodology and chosen visualizations for portfolio analysis, laid out in detail in Chapter Eight, to two real portfolios, helicopter and satellite. This demonstration included descriptors such as percentage of programs at Milestones B and C, number and type of breaches, indicators to include unit cost, percentage of funds remaining, and percentage of programs with any quantity change. We also looked at multimetric charts that provide a more aggregate perspective on the performance of the two portfolios. The most significant similarity between the two portfolios is that both seem be improving on certain metrics and at the aggregate level in recent years. The two portfolios show some differences as well as some similarities. The helicopter portfolio appears to show a gradually maturing (and possibly aging) portfolio that experiences some improvement in unit cost growth and number of breaches over the assessment period. The satellite portfolio, on the other hand, has more year-to-year changes in composition and somewhat less change in overall portfolio status over the assessment window. However, the satellite portfolio still has some programs that experience extended periods of poor performance especially in the years between 2007 and 2010.

This chapter focused primarily on describing the visualizations used for an analysis of either portfolio and did not conduct a full assessment of either. One important lesson here is the importance of viewing multiple metrics from different perspectives to better understand patterns and trends of portfolio status and future risk. Single metrics do not provide a complete picture of portfolio performance. The interpretation of performance metrics must also be done in the context of the descriptive metrics, especially awareness of programs moving in and out of the portfolio, the potential for one or two programs to dominate the results of portfolio metrics, and the size of the program and funds remaining as a measure of future portfolio risk. In addition, the kind of analyses demonstrated in this chapter can identify results that can then be explored in more detail. In the next chapter, we go one step further in providing a sample expanded narrative of the helicopter portfolio based on our observations from the metrics and visualizations shown here.

CHAPTER TEN

Expanded Narrative of the Helicopter Portfolio

The previous chapter outlined an initial portfolio analysis presentation, which visualizes the "what" of a portfolio's status in the context of the analysis's initial objectives (in our case, cost and schedule risk indicators). The analysis and visualizations allow for a repeatable and auditable process to track portfolio status indicators over time or across various portfolios. Inevitably, however, a policymaker or decisionmaker will want to delve into "why" portfolio trends or patterns have emerged to adjust his or her policies or priorities accordingly, and to understand whether near-term action can mitigate future portfolio risk. This examination can take many forms depending on the questions asked. If certain programs appear to be the driving force behind overall portfolio trends, a program-based root cause analysis may be required.[1] Other questions may require revisiting the portfolio analysis objectives to broaden the overall data and metrics collection needs. In this chapter, we provide an example narrative that arose from questions inspired from observed unusual or interesting trends within the helicopter portfolio analysis results. Although we did not conduct a comprehensive root cause analysis for each program in the portfolio, we did use general root cause methods to pinpoint cost growth events for the portfolio and to identify both the individual program performance issues and external forces or trends that may have driven those events. The major categories of potential policymakers' questions include greater contextual understanding, further examination into the portfolio analysis cost and schedule risk objectives, and further potential analysis inspired by the observed trends within the portfolio analysis.

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1 For a comprehensive methodology on performing root cause analyses of defense acquisition programs, see Irv Blickstein, Jeffrey A. Drezner, Brian McInnis, Megan McKernan, Charles Nemfakos, Jerry M. Sollinger, and Carolyn Wong, *Methodologies in Analyzing the Root Causes of Nunn-McCurdy Breaches*, Santa Monica, Calif.: RAND Corporation, TR-1248-OSD, 2012.

Providing Further Context

Although the descriptive metrics provide a general context for many of the performance metrics, additional details may be required to provide a greater, more nuanced picture. For example, what constitutes poor performance in terms of cost growth for a portfolio with many pre–Milestone C developmental programs may be different for a portfolio with many programs that have already entered full-rate production. The helicopter portfolio included 13 programs reporting between the years 2002 and 2012. During that time, some programs were initiated, others cancelled, and others finished reporting. Only five of the programs were actively reporting for the entire period. For this reason, many of our metrics are discussed as a percentage of programs in the portfolio that carry specific attributes. Key attributes of this portfolio are displayed in Table 10.1 and include the following:

- The portfolio contains a mix of force application (73 percent) and logistics (27 percent) platforms.
- The majority of active programs in the portfolio were mature (past Milestone C) by 2012.
- Army- and Navy-managed programs only are included (no Air Force-managed programs reported).
- Three programs with developmental and modified COTS acquisition strategies were cancelled during the observed time period.
- All actively reporting programs are modifications, upgrades, or evolutionary increments of existing military airframes.

Over time, the helicopter portfolio composition shifted from mostly force application to more logistics programs (see Table 9.1 for a view of the changing composition of the portfolio over time). In part, this shift may have resulted because the majority of the Army's rotary aviation portfolio now resides in the utility and cargo aviation fleets, and future plans for the portfolio are concentrated on sustainment, recapitalization, remanufacturing, and incremental modernization of existing fleets. Overall, DoD has only three new aircraft slated for production in the foreseeable future: the MH-XX replacement for MH-60R and S variants, the VXX presidential helicopter, and the Armed Aerial Surveillance (AAS), a replacement for the OH-58D Kiowa Warrior that is currently a pre-MDAP.[2]

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[2] For additional details, see "Annual Aviation Inventory and Funding Plan, Fiscal Years (FY) 2014–2043," May 2013. Notably, the AAS will be part of the Army's Future Vertical Lift program. The program will develop four different size aircraft that will share common sensors, hardware, and other technology. The new aircraft will replace the Army's UH-60 Black Hawk, AH-64 Apache, CH-47 Chinook, and OH-58 Kiowa helicopters. See "U.S. Army Future Vertical Lift Helicopter Reinvention Prototypes Will Be Flying in 2017," *Next Big Future*, January 31, 2015.

Table 10.1
Helicopter Portfolio Overview

Program Name	Service	Program Type	Helicopter Type	Status as of 2012
Comanche	Army	Developmental	Force application	Cancelled (2003) because of Army decision that the aircraft no longer met force requirements; costs were also an issue
VH-71	Navy	Modified COTS (AgustaWestland AW101)	Force application	Cancelled (2009 because of poor cost and schedule performance
ARH	Army	Modified COTS (Bell 407) with nondevelopmental mission equipment packages	Force application	Cancelled (2008) because of poor cost performance and test failures
Longbow Apache	Army	Modification/upgrade of existing AH-64	Force application	90 percent complete, stopped reporting in 2011
LUH	Army	COTS (non-developmental)	Logistics	90 percent complete, stopped reporting in 2012
UH-60M Upgrades	Army	Modification/upgrade of UH-60	Logistics	Milestone C (2001)
MH-60S	Navy	Modification/upgrade of SH-60B	Force application	Milestone C (2002)
MH-60R	Navy	Modification/upgrade of SH-60B	Force application	Milestone C (2006)
CH-47F	Army	Modification/upgrade of CH-47D	Logistics	Milestone C (2004)
H-1 Upgrades	Navy	Modification/upgrade of UH-1Y and AH-1Z	Force application	Milestone C (2008)
CH-53K	Navy	Evolutionary increment of CH-53E	Logistics	Milestone B (2005)
AH-64E Re-manufacture	Army	Modification/upgrade of AH-64	Force application	Milestone C (2010)
AH-64E New Build	Army	Modification/upgrade of AH-64	Force application	Milestone C (2010)
VXX/VH-92	Navy	Variant of H-92 Superhawk military transport	Force application	Future program; contract award for development in 2014
AAS	Army	Replacement or upgrade for OH-58D Kiowa Warrior	Force application	Pre-MDAP
MH-XX	Navy	Replacement for the MH-60R and S	Force application	Future program; capabilities-based assessment held 2013

NOTES: The gray-shaded programs in the top five rows are those that are either greater than 90 percent complete (and so no longer reporting) or were cancelled. The white programs are current, active programs. The three orange rows at the bottom of the table are developmental and pre-MDAP programs.

Overall, judging by these attributes, we can characterize the current active helicopter portfolio as a mature portfolio with a reasonably well-diversified contracting base (having more than a single contractor involved in the procurement of different aircraft in the portfolio can lower procurement risk compared to dependence on single source) and fairly low technical and contract risk.[3] The increasing maturity of the overall portfolio is due to the maturing of the programs in existence, no new entrants, and termination of several of the newer entrants (ARH and VH-71). The only Milestone B program is CH-53K. Although this indicates more stability for the portfolio, portfolio maturity may also be problematic because it suggests a lack of new development, which could be a source of risk in the future. It is worth noting that the CH-53K, although technically an evolutionary program, is significantly different from its predecessor, adding some new risk but also new development.

Spending Trends

One metric that can provide context into the evolution of a portfolio over time is spending trends. Spending rates may be relevant to a portfolio analysis for a few reasons. If spending rates are steep but there is no evidence of any other technical problem, then this may not be a signal for concern. However, in some cases, steep spending rates may be a sign of underlying technical problems that must be addressed. In other cases, rapid spending may be a warning sign that a program is likely to run out of funding before completion. Because it may be a signal of current or future problems, programs with high rates of spending may warrant additional attention or investigation. Figures 10.1 and 10.2 show the percentage remaining for both RDT&E and procurement funding, which reveals not only how much is left for individual programs in 2012 but also the rate at which they are spending. These figures can be a first step in helping answer the following potential policymaker questions:

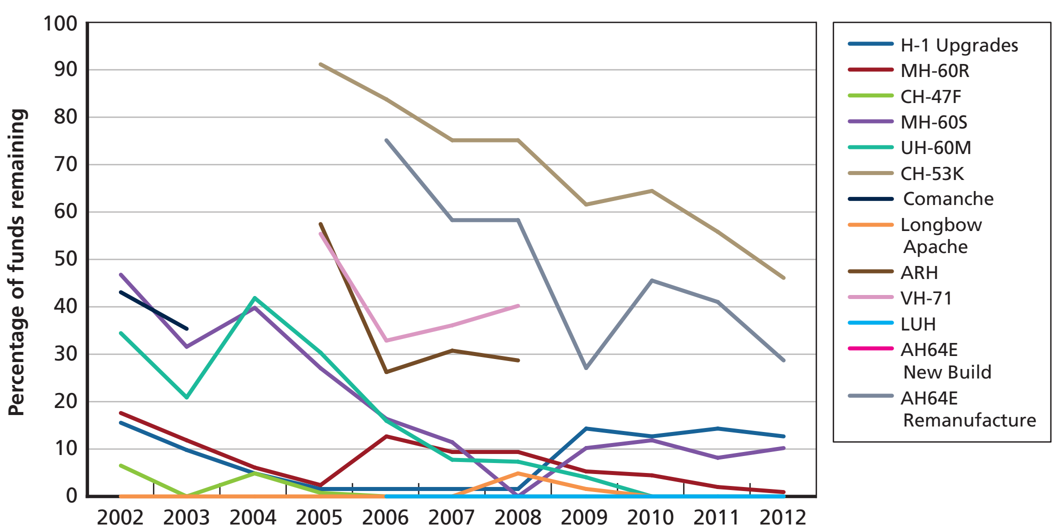
Percentage of RDT&E funds remaining (Figure 10.1)	Programs seem to have spent most/all of their RDT&E funds. Which programs still have some funds remaining? Do we know anything about how those funds will be used? Does the amount of remaining RDT&E funds appear adequate given the acquisition phase of the program? Which programs are spending at a faster rate and why? Does this indicate technical problems?

[3] These assumptions are based on evidence in the literature suggesting that evolutionary acquisition strategies (incremental modifications of existing platforms) typically have lower technical risks and that a firm fixed-price contract places more of the cost performance risk on the contractor.

Percent procurement funds remaining (Figure 10.2)	Percentage of procurement funds remaining appear to be declining. Which programs have procurement funds remaining? Which programs seem to be spending much faster/slower than average? Do these programs share any other characteristics? Are the programs spending in a manner commensurate with quantity of aircraft (or vehicles, weapons, etc.) left to procure? Which programs have spent all nearly all of their procurement dollars, and what is likely to happen to them once they finish spending their money?

As shown in Figure 10.1, AH-64E Remanufacture, CH-53K, H-1 Upgrades, MH-60S, and MH-60R still have RDT&E funds. As CH-53K is still in EMD, it is not surprising that it has almost 50 percent of its RDT&E funding still available. The AH-64E Remanufacture also has a significant portion of its RDT&E funding left. Specifically, the program received additional RDT&E funds in 2010 to support additional labor costs to improve the AH-64E's combat capability.[4] The other three programs have far less RDT&E funding remaining but still have several RDT&E lines of effort as of 2012. A few other programs appear to have received new RDT&E funds midway through their program life cycle. For example, the UH-60M and MH-60S received additional RDT&E funds in 2004. For the MH-60S, these additional funds went to additional testing and to incorporate some additional design improvements.[5] For the UH-60M, the additional funds supported several improvements to the

Figure 10.1
Percentage of RDT&E Funding Remaining, by Program, 2002 Through 2012



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[4] Department of Defense, *AH-64E Remanufacture*, Selected Acquisition Report, December 2010c.

[5] Department of Defense, *MH-60S*, Selected Acquisition Report, 2004a.

UH-60M, including Common Avionics Architecture System (CAAS), Fly-By-Wire and Full Authority Digital Engine Control.[6] In 2008, the H-1 Upgrades also received additional RDT&E funds, which went toward a redesign as well as the development and testing of new software.[7] Finally, the MH-60R experienced a smaller increase in RDT&E funding in 2006, which also went toward design improvements.[8] Another potentially important insight from Figure 10.1 is the flatness of the H-1 Upgrades and MH-60R RDT&E spending curves. These could be considered worrisome trends, as the flat curve could indicate that the programs are not conducting the necessary RDT&E activities for which the money was allocated—a signal of potential program problems or schedule delays. An analyst noting these flat curves might choose to investigate the RDT&E progress of these two programs in more detail.

Some additional consideration of ongoing R&D within the helicopter portfolio is useful because it provides insight into the future of the portfolio, including potential sources of risk and stability going forward. For example, the H-1 Upgrades will include the development of a new cabin. However, the first AH-1Z New Build cabin is reported to be one year late and experiencing cost overruns, which may signal risk that the program will require additional fund increases from its uptick in 2008. The MH-60R is using its RDT&E funds to increase the reliability of its Airborne Low Frequency Sonar and continue its Automatic Radar Periscope Detection and Discrimination SDD program. Finally, the MH-60S is developing the LAU-61G/A Digital Rocket Launcher with Advanced Precision Kill Weapons System and is also conducting tests and operational assessments of the AN/AES-1 Airborne Laser Mine Detection System, AN/AQS-235 Airborne Mine Neutralizer System and Organic Airborne Surface Influence Sweep (OASIS). In March 2012, the CNO ended efforts to integrate the OASIS system and the Sonar Mine Detection Set on the platform, which may have freed up additional funds for the program.

Figure 10.2 shows the rates of procurement spending for all programs. As of 2012, the only program that is not spending procurement dollars (besides the programs that have been completed or cancelled) is the CH-53K program, which is in development. As shown by the graph, the UH-60M, H-1 Upgrades, MH-60R, Longbow, AH-64E Remanufacture, and MH-60S appear to be spending their procurement dollars at similar rates, even though they differ on the percentage left as of 2012. The Lakota light utility helicopter (LUH), however, is spending its procurement funds at a faster rate, but is nearing program completion. An analyst might be concerned about this faster rate of spending, but the fact that the program is close to completion may mitigate this concern. The AH-64E New Build also appears to be spending its procurement funds somewhat faster than other programs, but only really in the past year or so. Since the

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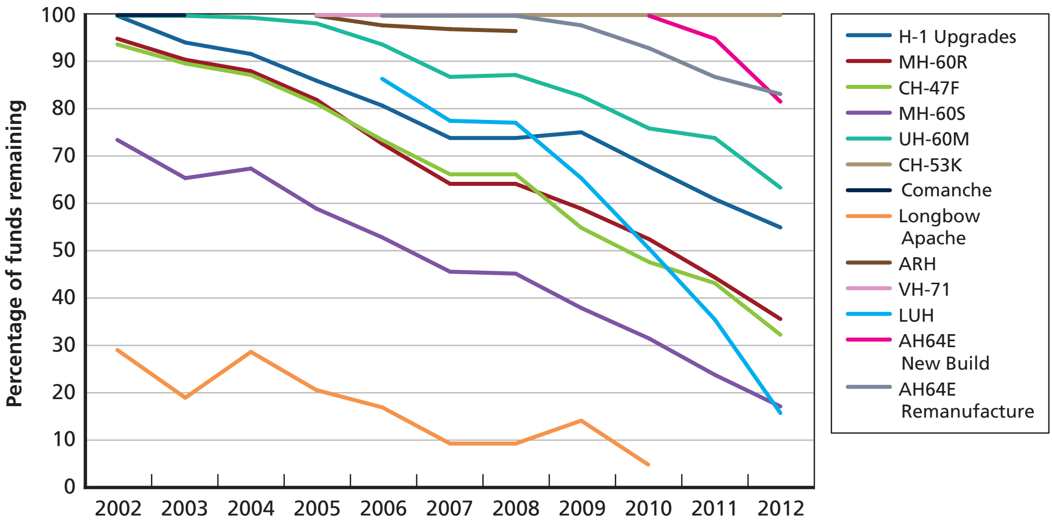
6 Department of Defense, *UH-60M*, Selected Acquisition Report, 2004b.

7 Department of Defense, *H-1 Upgrades,* Selected Acquisition Report, 2008a.

8 Department of Defense, *MH-60R*, Selected Acquisition Report, 2006.

Figure 10.2
Percentage of Procurement Funding Available, by Program, 2002 Through 2012



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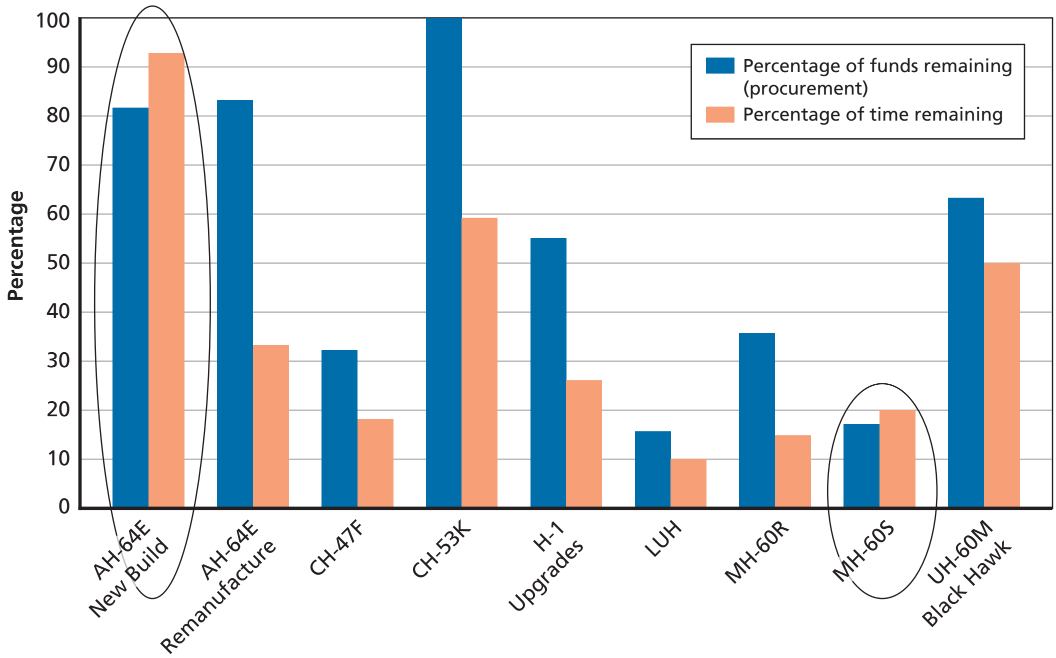
program only recently passed Milestone C, it is really too soon to tell if this represents a long-term trend. However, if this faster rate of spending were to continue, this might be a signal of possible problems, since it could compromise the ability of the program to meet procurement objectives. To fully understand the implications of these observations, an analyst would need to conduct a more complete investigation of each individual program than we do in this report. This additional analysis would still be part of the portfolio analysis process, as the process is one that has many layers and that can be taken as far as analyst needs or desires.

Figure 10.3 shows the percentage of remaining procurement funding versus remaining program time according to the anticipated time line for the program. This metric is primarily an indicator of the need for more in-depth assessment. Possible follow-on questions could be:

- Is the remaining funding adequate for the remaining quantities?
- Is there sufficient time to procure the remaining quantities?

In addition to the above questions, Figure 10.3 allows us to make several observations about the rate of spending of various programs within the portfolio that were active as of 2012. Only two programs, the MH-60S and AH-64E New Build, have a smaller percentage of procurement funds remaining than they do time remaining. This may be concerning, since it suggests that these programs may run out of funding

Figure 10.3
Percentage of Procurement Funding Remaining Versus percentage of Time to Program Completion



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before procurement is complete.[9] For the AH-64E New Build, the large percentage of both funding and time remaining suggests that it is too soon to be overly concerned about the status of this program. For the MH-60S, the difference between percentage of time and percentage of procurement funds remaining is small and the program is nearing completion, again tempering concern. For other programs in the portfolio, the percentage of funds remaining greatly exceeds the percentage of time remaining. For example, the CH-53K has 100 percent of its procurement funds remaining but only 60 percent of its time remaining. This difference may raise the question of whether the program will be able to spend all its funds and procure needed quantities before its planned end date.

Deeper Examination into Cost and Schedule Risk: Unit Cost and Breaches

Over the 11-year period for which we gathered data, the overall status of the portfolio seems to improve along the dimensions considered by our portfolio metrics.

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[9] Of course, there is less concern that the project will end with funds remaining, since if funding remains when a program is near completion, it can more easily be reallocated. That said, a rate of spending that is too slow may also be worrisome, if it suggests that a program is not going to meet schedule deadlines or that it will leave unused money on the table.

Specifically, we observe some improvements in our portfolio metrics between 2008 and 2009 and 2012. In particular, average portfolio cost growth has decreased significantly. However, as we will discuss more in our analysis of the portfolio, although the helicopter portfolio does show some improvement in terms of unit cost growth and schedule, a complete portfolio assessment considers the portfolio's performance on many dimensions, not just one or two. Through our measurement and visualizations of portfolio indicators, we identified the following areas and questions for further analysis:

Unit cost growth	What programs are driving high unit cost growth between 2007 and 2009?
	Why does unit cost growth for the portfolio appear to decline over time and what is driving that decline?
	What factors at the program-level appear to be driving program outcomes and how does this affect our assessment at the portfolio level?
	What is the effect of rebaselining on this metric?
	What is the relationship between unit cost growth and other indicators?
Breaches	Which programs have the most breaches and what types? Are there any patterns in breach types (e.g., breach types that seem to affect all programs or no programs?)
	Are there any patterns in root causes or drivers of observed breaches?
Multimetrics	What drove the large shape of the radar chart in 2004? How was this corrected in 2005?
	Why does the performance/shape size appear to grow in 2006, 2007, and 2008?
	What program or programs helped turn this around starting in 2010? How were these changes accomplished? Was it because programs ended? Policy changes? Rebaselines?
	Comparing 2003, 2007, and 2012: What explains the very different shape in 2003? How can we compare this to 2007 and 2012

Unit Cost Growth and the Effects of Rebaselining

In some years over the time period observed, the portfolio appeared to have higher than average unit cost growth; for example, changes in APUC and PAUC between 2007 and 2012 were statistically significant, and percentage unit cost growth in 2008 and 2009 was statistically different and higher than cost growth in other years. To understand the causes of this cost growth, we investigated the performance of individual programs. The difference between 2008–2009 and 2012 may even be underestimated in our data because the VH-71 program was reporting low estimated cost growth in the SARs and DAES; however, government changes to capability requirements led to a restructured total program estimate that was nearly twice the baseline estimate. The VH-71 negative cost growth reported in 2008, which is interpreted as strong cost performance if only viewed from the perspective of a single metric, results only because of an increase in quantity without a parallel increase in funding. The VH-71 program was subsequently cancelled in 2009 under heavy political pressure.[10]

[10] Senator John McCain, for example, was vocal in his frustration at the program's rising costs. "We can't afford," he asserted on February 24, "to have a helicopter built for the president of the United States that costs more than

The ARH program, which suffered from contractor management issues, test failures, delays, and cost growth in excess of 40 percent, was also driving some of the high portfolio unit cost growth in the 2008–2009 time period. Its cancellation in 2009 helped to improve the overall portfolio status with regards to the cost metrics.

The H-1 Upgrades program was also performing poorly in 2008 and suffered an APUC breach above 15 percent; however, this program was not subsequently cancelled but instead was rebaselined. Unlike the ARH and VH-71 programs, internal performance issues were not the main reasons for high cost growth for the H-1 Upgrades. Rather than significant program performance issues, there were external demand forces driving the changes to this program and necessitating a new baseline cost estimate. The main driving force was changes to the force structure needs of the Marine Corps, requiring additional aircraft quantities. The existing inventory of AH-1Z available for remanufacture was less than needed for conversion, and thus the program was restructured to build entirely new platforms to meet the inventory shortfall, according to its SARs. This example highlights the caution that must be taken in interpreting some of the cost growth metrics.

Finally, the AH-64E Remanufacture suffered a high unit cost growth and an APB breach for both APUC and PAUC in 2009. In this case, however, the breach was less a performance-driven issue than a change in how costs for the program were reported. This change resulted in a high unit cost growth in that year but not a systemic or lasting problem. Subsequent improvement in the program contributed to the overall improved cost-growth performance of the helicopter portfolio in later years.

To reiterate a point made above, however, one must not focus on a single metric without understanding its context and how the particular metric is calculated. At the portfolio level over the entire time period, unit cost growth appears to be lower in 2012 than in 2002 with more significant changes when we compare 2008 and 2009 to 2012. However, although portfolio unit cost growth, when compared to the original baseline, appears to decline between 2002 and 2012, this may not reflect an actual improvement in unit cost growth performance because of rebaselines that also occur over this same period. Table 10.2 shows the rebaselines that occurred from 2002 to 2012. In fact, nearly all of the programs had at least one change to their current baseline during the time period observed, and about half of the programs also had a change to their original baseline, which can further affect apparent changes in unit cost growth. In fact, the MH-60R, UH-60M, and the H-1 Upgrades programs have all had four or more baseline changes over the 10-year period.

The decision to establish a new baseline may follow both positive and negative program events and changes including APB breaches, revised cost estimates at mile-

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Air Force One." Christopher J. Castelli, "Navy, Lockheed Mum Amid Revelations of Soaring VH-71 Costs," *Inside the Navy,* March 9, 2009. The program was cancelled after a comprehensive program review in FY 2010. For further information, see Dan Taylor, "Navy Issues Stop-Work Order on VH-71 Presidential Helo," *DefenseAlert*, May 15, 2009.

Table 10.2
Program Current Baseline Changes, 2003 Through 2012

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total Re-baselines (Current)
H-1 Upgrades		APB breachers			APB breach/ restructure		Nunn-McCurdy breach cleared/ quantity change	New SCP			4
MH-60R	New cost estimate	Changed procurement strategy		APB breach/ requirements change				APB breaches/ quantity change			5
CH-47F								Breach			1
MH-605		APB breaches						Nunn-McCurdy breach cleared/new cost estimate			2
CH-53K	Pre-Milestone B									New cost estimates	1
LUH		Pre-Milestone B			Contract change						1
UH-60M	Changed procurement strategy	APB breaches		Added upgrade					Increased quantity		4
Comanche	New ICE					Cancelled					1
Longbow			Requirements changes						Stopped reporting		1
ARH	Pre-Milestone B							Cancelled			0
VH-71	Pre-Milestone B							Cancelled			0
AH-64E remanufacture		Pre-Milestone B						Program splits into remanufacture and new build			1
AH-64E new build				Pre-Milestone B							0
No. f programs rebaselined	3	2	3	2	2	1	1	5	1	1	21

stone approvals, changes to the contracting or procurement strategy, or changes to the estimated quantities.[11] In the helicopter portfolio, half of the programs that issued a new baseline during the time period observed did so (as required) in response to either a Nunn-McCurdy or an APB breach. However, the other half of observed rebaselines occurred without any precipitating breach.[12]

Rebaselining has the effect of making unit cost growth look lower because it raises the baseline estimate. When looking at the portfolio as a whole using the current baseline as the evaluative metric, unit cost performance is likely to show signs of improved performance in years following a large percentage of program rebaselines. For example, between 2010 and 2012, seven of the active programs in the portfolio (10 in 2010 and nine in 2011 and 2012) issued a new current baseline. It is important to note that these rebaselines occurred over the same period in which we observed declining percentage unit cost growth in both the APUC and PAUC. The rebaselines in this period may contribute to a misleading view of unit cost growth. Using the original baseline to calculate unit cost growth in cases where rebaselines have occurred provides a more accurate picture of unit cost growth. Looking at the same 2010 to 2012 period using the original baseline, for example, will tell a somewhat different story about unit cost growth than the current baseline graphs shown previously. Figure 10.4 shows the trend in unit cost growth using the original baseline. Although the current baseline chart shown in Chapter Nine shows a decline in unit cost growth in recent years, the original baseline graph does not show the same trend. Instead the chart suggests that the PAUC for the portfolio as a whole has remained largely the same. The median does not appear to change much, although the range does vary from year to year. In this case, the best cost-growth performance appears to be in 2005 and 2006, with 2007 through 2011 slightly higher (and these differences are statistically significant at $p < 0.01$). However, the original baseline chart still tells a "good news" story about the performance of the portfolio. Clearly, the percentage unit cost growth of the portfolio has improved since the period from 2002 to 2004. It has also been remarkably steady in recent years, even when the beneficial effects of rebaselining are factored in. This graph could also be used to allay the policymaker fears about runaway cost growth, at least in this portfolio program.

The discussion of the percentage unit cost growth performance of the portfolio measured from the original baseline suggests that it is important to consider both indicators when evaluating portfolio risk. An analyst should expect to see low portfolio

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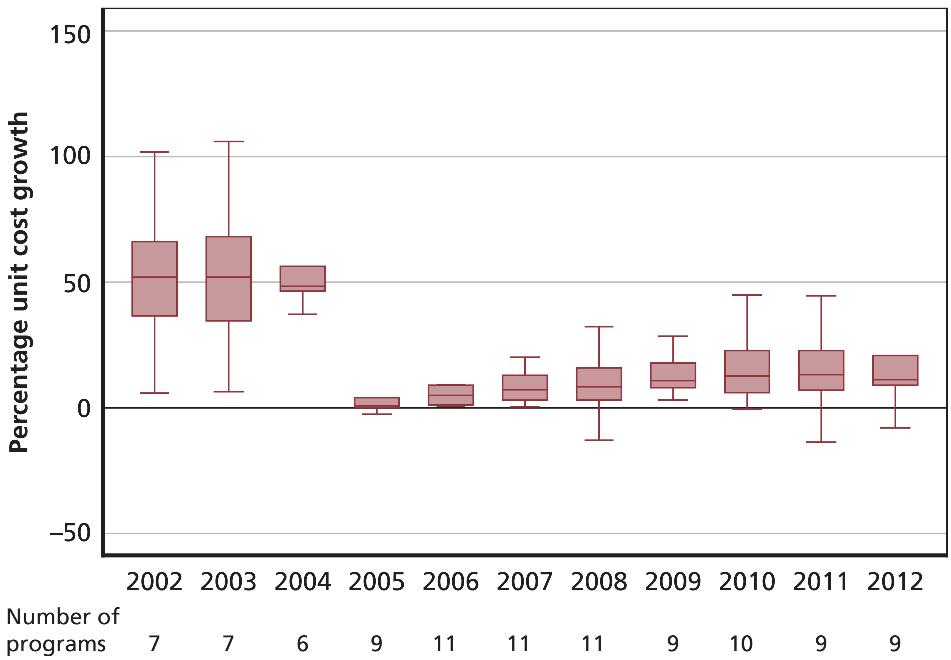
[11] A program may have a breach or quantity changes from the current baseline for more than one year before restructuring the program and issuing a new baseline.

[12] According to DoD Instruction 5000.02 "Operation of the Defense Acquisition System," January 7, 2015, Programs may rebaseline under the following circumstances: At milestone, full-rate production, and full deployment decisions; a major program structure approved and fully funded by the Milestone Decision Authority (MDA); or if the MDA concludes that "fact-of-life program changes" deem management to the existing baseline impractical. Programs are explicitly prohibited from rebaselining simply in order to avoid a breach.

Figure 10.4
Percentage Unit Cost Growth, PAUC Original Baseline, Helicopter Portfolio, 2002 Through 2012



NOTES: Changes between 2004 and 2005–2010 along with changes from 2005 to 2009–2011 are statistically significant at $p < 0.05$. MH-60S omitted 2005– 2007, 2012; ARH omitted 2008; VH-71 omitted 2006–2007; AH-64E Remanufacture omitted 2010 and 2012.

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unit cost growth using the current baseline following a period where many programs have restructured to new current baselines. The analyst will not see this same improvement and will get a more accurate picture of performance on unit cost growth when the original baseline is used to calculate unit cost. Although it may be misleading, looking at unit cost growth using current baselines can still be valuable for an analyst. For example, the fact that restructuring and rebaselining has occurred may remove some program risk if funding is better aligned with quantity changes or new cost and schedule estimates. On the other hand, high portfolio unit cost following a period where many programs have restructured to a new baseline may be a warning sign that portfolio performance is decreasing.

It is difficult to identify root causes for unit cost growth across the portfolio, especially as related to program management. There may potentially be a relationship between lower cost growth and maturation of programs in the portfolio with many in

production and few in development by 2012. However, we did not observe a relationship within this set of data.

We would assume that, in general, modifications or increments of existing platforms should have lower risk than revolutionary development programs across a number of technical and management dimensions. Only one program in the helicopter portfolio (Comanche) could be a considered a new development program. All the other programs in the portfolio are modifications of existing military or commercial platforms, or increments/evolutionary developments of existing helicopter programs. In fact, platforms in the CH-53 and CH-47 family have been in production since the 1960s. However, two of the programs that were cancelled for poor cost performance (VH-71 and ARH) were modifications of COTS platforms. These programs may have still been "developmental" in terms of the unproven integration of different mission packages/systems into a commercial platform. Although other programs are increments, they still incorporate new developmental technologies. In the case of the CH-53K, the changes planned compared to its predecessor are significant. The new helicopter is planned to have twice the lift capacity of the previous variant and makes other advances as well. Thus, although it is an evolutionary program, there is still much new development (and therefore time and risk) involved.

APB and Nunn-McCurdy Breach Trends

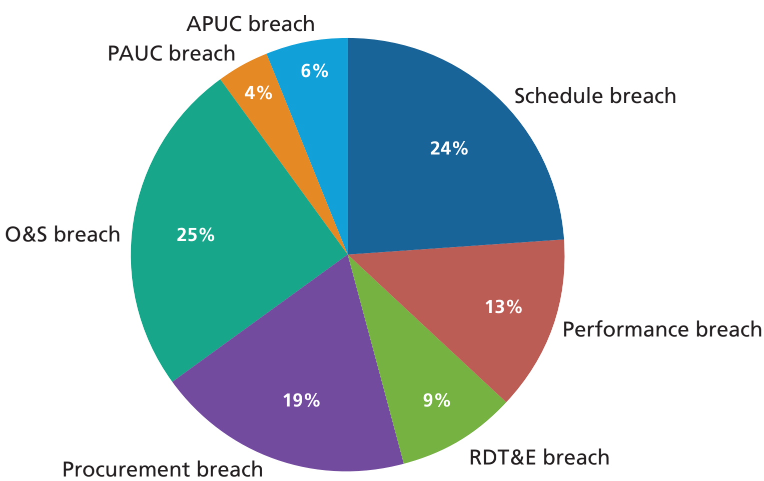
The collection of APB and Nunn-McCurdy breach data provides a key example into why the context of current policy can affect a metric's outcomes. During our portfolio's time frame, the policy on how Nunn-McCurdy breaches were defined and thus reported changed. In the FY 2006 NDAA (P.L. 109-163), DoD was directed to measure cost growth against the original baseline *in addition* to the current baseline, which it has traditionally been measured against. Because of this reporting change, more programs generally incurred more Nunn-McCurdy breaches post-2006. The rules one uses for counting these breaches pre- and post-2006 greatly influence the results.[13] For our analysis, we simply recorded the Nunn-McCurdy breaches as they were reported within the SARs to reflect policy priorities at the time. Other analysts may wish to normalize the definition of Nunn-McCurdy breach and perform additional calculations. In addition, another key issue when recording Nunn-McCurdy breaches over time is that programs may report the same breach for multiple years until it has been restructured. We took this into account in our analysis. For APB breaches, we similarly record them as they were reported in the SARs (e.g., if the SARs reported an APB breach, we

[13] For additional discussion on this issue and a proposed methodology for normalization of Nunn-McCurdy breach data collection, see Arena et al., 2014a, pp. 59–105.

do likewise here).[14] For the helicopter portfolio, the reduction in the number of both APB and Nunn-McCurdy breaches is statistically significant when comparing 2012 with 2007 and 2008 but not when comparing 2002 and 2012. As discussed in the section above on unit cost, program breaches may drive a restructuring, rebaselining, or cancellation of the program (more likely in the case of a Nunn-McCurdy breach). The cancellation of the ARH and VH-71 programs by 2009 and the restructuring of four other programs in 2010 likely contributed to a reduction in breaches.

When we looked for patterns in the types of breaches within the portfolio over this time period, we found that the most common type of breaches were O&S or schedule breaches, accounting for half of the total breaches as Figure 10.5 shows. Cost breaches (PAUC and APUC) make up less than 10 percent of the observed breaches in this portfolio over the time observed. These results are not totally unexpected, as in a more mature portfolio we would expect to see more procurement and O&S breaches and fewer RDT&E breaches. Over half of the schedule breaches and nearly three-quarters of the O&S breaches are attributable to three programs that are being procured through a single manufacturer (MH-60S, CH-53K, and UH-60M). Some O&S breaches appear to be due to changes in platform service life. The service lives for MH-60S and UH-60M were extended from 20 to 25 years, and this may have driven the O&S breaches these programs experienced. Schedule breaches for the CH-53K were due to component test delays (late parts deliveries) and qualification test failures.

Figure 10.5
Types of APB Breaches, Helicopter Portfolio, 2002 Through 2012



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[14] For specific definitions of APB breach types, see Chapter Nine or William Parker, Defense Acquisition University, *Program Manager's Toolkit,* January 2011.

These same program delays and testing issues may have also contributed to the O&S breaches experienced by CH-53K. Some of the schedule breaches for the MH-60S can be attributed to labor actions and strikes in 2006. There were no MILCON or O&M breaches reported for this portfolio; however, none of the programs had associated acquisition O&M funding (although they did have other types of O&S funding),[15] and only three programs in the portfolio had associated MILCON funding. Two of those programs (Comanche and VH-71) were cancelled before entering Milestone C. The absence of MILCON and O&S funding for most programs may reflect some of the unique characteristics of this portfolio; i.e., most programs are upgrades and modifications of existing platforms, thus much of the military infrastructure to support these platforms is likely already in place.[16]

In terms of Nunn-McCurdy breaches, several programs that incurred significant and critical breaches (see Table 10.3). The Comanche, ARH, and VH-71 programs (all three Force Application programs) were cancelled shortly after reporting a Nunn-McCurdy breach. For the H-1 Upgrades program, the unit cost growth is primarily a result of increased prime contractor labor and material cost, Government Furnished Equipment costs, additional Non-Recurring Engineering costs, and correction of deficiencies from Operational Evaluation Phase 1. The unit cost increase also takes into account additional costs resulting from the Marine Corps expanding the H-1

Table 10.3
Nunn-McCurdy Breaches, Helicopter Portfolio, 2002 Through 2012

Program	Type of Nunn-McCurdy Breach	Year
Comanche	PAUC critical (current baseline)	2002
MH-60S	PAUC significant (current baseline)	2005–2012
ARH	APUC and PAUC significant (current baseline)	2007
H-1 Upgrades	APUC and PAUC significant (current baseline)	2008
VH-71	APUC and PAUC critical (current baseline)	2009
Longbow	APUC and PAUC critical (current baseline)	2009

NOTES: The breach status for H-1 Upgrades reflected in the table is based on the prior APB dated July 2007, which was the current APB when Congress was notified of the significant Nunn-McCurdy breach to the APUC in December 2008. The prior APB of July 2007 was revised on December 22, 2008, to reflect approval of the program's Milestone III decision. Subsequently, changes in the procurement phasing of UH-1Y and AH-1Z remanufacture, and AH-1Z new build, increased the PAUC current estimate by approximately 1 percent, but this does not constitute a breach compared to the current approved APB of December 2008.

15 O&M costs are a type of O&S costs incurred for using and supporting the system, such as personnel, maintenance (unit and depot), spares, and training. MILCON costs are associated with construction.

16 See Table 9.5 for a full account of breaches by program.

Upgrades procurement objective by 69 aircraft (23 UH-1Y and 46 AH-1Z) to a total of 349 aircraft. This change increased not only the overall procurement cost of the program but also the average unit cost, since the additional AH-1Z aircraft are in excess of the existing inventory of AH-1W airframes. As a result, the additional AH-1Z aircraft will need to be built new without the cost benefit of remanufacturing. The Longbow breach in 2009 was addressed by splitting the program into two pieces.

Investigating Trends in Multimetric Visualizations

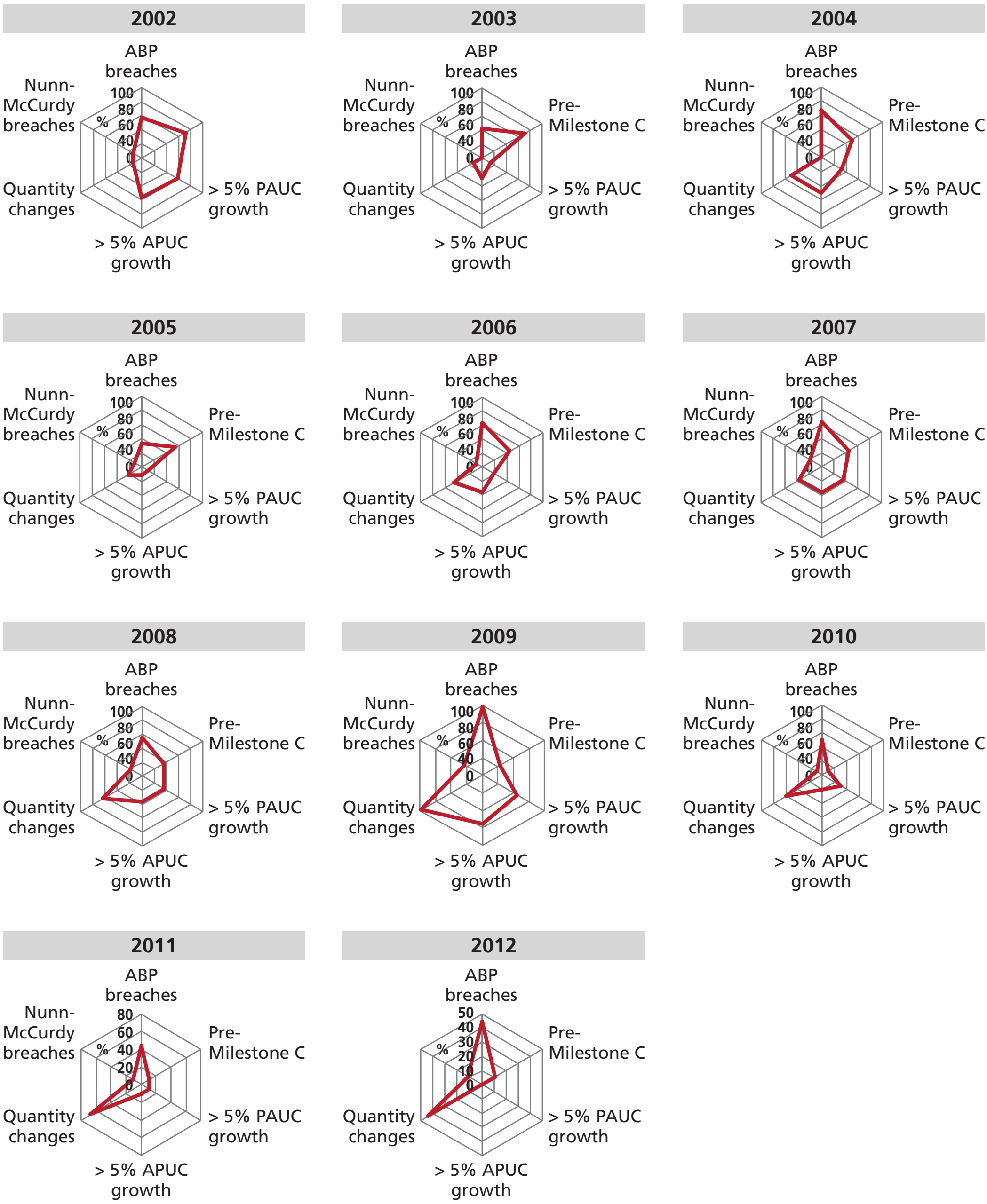
With multimetric visualizations, it may be necessary to examine the relationships between the various metrics and uncover potential outside factors that may have contributed to trends or patterns over time. In our case, the changes in shape of our "radar chart assessments" shown in Figure 10.6 inspired several questions, outlined above, on which a policymaker may require additional information.

The larger shape in 2004 in Figure 10.6 appears to have resulted because the number of programs in the portfolio dropped to six, and therefore the issues encountered by those six programs became more heavily influential within the overall portfolio. By 2005, three new programs began reporting SAR data, which led to the significantly changed shape from the previous year because newly reporting programs were typically at or near the baseline for cost metrics and would not have recorded quantity changes from the previous year. Between 2006 and 2008, the ARH was a big driver for the increase in the size of the shape in the radar chart, with five breaches alone recorded for this program in 2007. Program cancellations of the ARH and the VH-71 improved the status of the overall portfolio in 2008 and 2009 as did the rebaselining of several ongoing programs within the portfolio. By 2012, the portfolio consisted of more mature and stable programs that reached production and Milestone C, which contributes to the smaller shape of the corresponding radar chart.

Potential for Future Cost Growth in the Portfolio

Positive trends in the helicopter portfolio appear to be driven by program-specific events and evolution rather than by improvements in management, execution, oversight, or systematic changes in underlying factors likely to affect program performance. As a result, it is difficult to predict whether the portfolio's recent improvement in unit cost growth will continue or reverse. Although the CH-47F had the highest cost growth of any of the active programs in the 2012 portfolio, the program appears to be executing well, excluding events outside the program's control. As of 2014, it was in full-rate production with multiple FMS customers and was awarded a Block II contract in March 2014. It is likely for this program that cost growth will remain stable unless affected by external events. If there is one program to look for unit cost growth in the next year, it might be the MH-60R because of proposed quantity changes—particularly if the quantity changes are not associated with adjustments to the APB. Another program that may need to be watched for potential cost growth is the CH-53K, which entered

Figure 10.6
Aggregate Portfolio Performance, Helicopter Portfolio, 2003 Through 2012



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flight testing in 2014 and has already incurred with some delays because of technical issues that will require some gear box redesign.[17] In addition, as noted above, the CH-53K includes significant changes from its predecessor, and this new development may bring with it new risks and potential costs. Furthermore, the program narrowly avoided a breach in 2009 because it increased the procurement quantity from 156 to 200 because of the increasing size of the Marine Corps authorized end strength. However, since the Marine Corps will be shrinking its force structure, the CH-53K may experience a breach when the production quantities are finally reduced to match the future smaller size of the Marine Corps.

Finally, new programs may enter the portfolio and affect the portfolio's unit cost-growth performance.

Helicopter programs that are currently in predevelopment stages may be sources of future portfolio cost growth. The VXX development program that will enter the helicopter portfolio in the near future is intended to provide the presidential helicopter with the capability to replace the cancelled VH-71 program. Given the previous political scrutiny on the VH-71, the VXX may also be a high-visibility program. The program is a modified military-off-the-shelf variant of Sikorski's H-92 Superhawk military transport. Although Canada's procurement of the aircraft has suffered from some delays and missed milestones, the maturity of the platform could potentially limit some technical risk in the VXX program. In addition, the EMD contract is an FPIF-type contract, which will limit some of the government's liability for cost growth. Another program in the pre-MDAP phase that could potentially contribute to portfolio cost risk is the AAS helicopter. This potential program is another attempt to replace the Army's Kiowa Warrior after the Comanche program was dropped in 2003.

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17 "First Flight of CH-53K Heavy-Lift Helicopter Delayed," *InsideDefense*, July 17, 2014.

CHAPTER ELEVEN

Summary and Way Ahead

Part Two of this report develops a methodology and set of metrics that can be used to characterize the status and risk of portfolios[1] of MDAP programs over time and across commodity types. As noted in the introduction, being able to easily summarize the status and performance of a set of acquisition programs is valuable to the defense acquisition community, because it allows analysts to understand and identify sources of risk, areas of vulnerability, lines of development where investment is needed, and areas of strength and strong program performance.

Summary

The report defines, explains, and demonstrates a portfolio analysis framework, which included the following steps: identify objectives, choose a portfolio type, select data and metrics, address data anomalies and challenges, calculate metrics, and visualize metrics. We provide a number of different data sources that could be used for analysis and ways to overcome some of the challenges associated with these data sources. The methodology also includes a large number of portfolio metrics and visualizations of those metrics that can be used to summarize the findings of a portfolio assessment. In selecting metrics, we chose a set of metrics that would comprehensively assess program and portfolio status and that captured many dimensions of program and portfolio risk and status. Having many different metrics is important to the portfolio assessment framework because, as we noted throughout, each metric must be interpreted in the context of others and no single metric provides a sufficient basis on which to evaluate a portfolio's performance. The visualizations we provide are also valuable, because they can help analysts interpret a given metric or set of metrics, particularly when the focus of the analysis is change in performance over time.

1 Subportfolios include smaller sets of MDAPs with similar characteristics. The analysis of a subportfolio allows us to study the status of these smaller sets of programs in more detail and to separate their status from the statuses of the overall portfolio of MDAPs and other subportfolios.

In addition to defining a methodology, we use the report to demonstrate and validate our approach and selection of metrics using several sample portfolios, chosen specifically to provide a robust test of the methodology and to allow for refinements as necessary. Our demonstration and application to the helicopter and satellite portfolios included descriptors such as percentage of programs at Milestones B and C and number and type of breaches, and indicators to include unit cost, percentage of funds remaining, and percentage of programs with any quantity change. We also looked at multimetric charts that provide a more aggregate perspective on the performance of the two portfolios. By discussing the two portfolios side by side, we were able to highlight similarities and differences between the two portfolios and to further highlight the value of specific metrics within the portfolio assessment process. Throughout the report, we focused largely on defining the methodology and discussing the metrics and did not fully complete the assessment by digging deeply into each program within the portfolio. In Chapter Ten, however, we did conduct a more detailed assessment of the helicopter portfolio, using additional graphs and our metrics to offer a more robust analysis of the status of this portfolio of programs. That chapter also provided some insight into questions raised in our initial discussion of metrics in Chapter Nine, including additional detail on the drivers of increases and decreases in unit cost, programs with APB and Nunn-McCurdy breaches, and the rates of spending of programs within the portfolio. This expanded narrative is a small example of how the methodology provided in this report could be used by members of the defense acquisition community to study and assess a set of acquisition programs and then graphically summarize the portfolio's overall status.

Way Ahead

This report provides a generalizable and repeatable portfolio assessment methodology that addresses the need of the defense acquisition community for a way to analyze and communicate the status of a set of acquisition programs. The methodology is valuable because it can be applied to any number of acquisition portfolios using a relatively straightforward approach and because we have included possible visualizations which will help in the interpretation of key metrics.

The work presented here can be expanded in several ways to make the methodology even more useful for analysts and to allow analysts to use the methodology to inform policymakers.

First, as noted throughout, this report has focused on the development and validation of the methodology for portfolio assessment rather than on the complete execution of the portfolio assessment itself. One next step would be to apply the methodology here to a larger number of portfolios, focusing more explicitly on the assessment phase of the analysis rather than so heavily on the methodology and the metrics. These

assessments could serve several purposes. Most important, they would provide insight into the status of a larger set of acquisition programs and allow analysts to provide a more comprehensive picture of the risk and performance of DoD's acquisition portfolio as a whole. Conducting a larger number of assessments would also facilitate cross-portfolio comparisons, which would allow analysts and policymakers to identify areas where additional investment or attention is necessary. Finally, the process of conducting many portfolio assessments using the methodology defined in the report will contribute to the refinement and improvement of the methodology itself as repeated use will highlight areas where additional metrics or alternative visualizations may be valuable.

Another way that the work here could be expanded builds off this notion of refining and improving the current methodology. Over time, the objectives and interests of policymakers and defense acquisition analysts are likely to change and evolve. They may become interested in different aspects of portfolio performance or in different metrics as ways to assess this performance. The methodology in this report can be easily refined and updated to reflect these new priorities and interests by collecting additional data, adding metrics, and developing new visualizations that can address emerging questions and concerns. Even in the near term, the methodology could be improved and refined by including additional metrics that we did not consider in detail for this report. One candidate would be the types of contracts and the share of contracts across various contractors. This specific metric would be valuable for providing insight into the status of the industrial base, but certainly other metrics could provide insight into other aspects of portfolio performance. Refinement of the methodology should not be done haphazardly, however, and would still require vetting of data sources, mitigation strategies to deal with data anomalies, and careful selection of visualizations that package the metrics' results for the policymaker.

Regardless of the specific direction it takes, the portfolio assessment methodology presented in this report should have wide and growing applicability within the defense acquisition community given the current fiscal environment. It provides a way for analysts and policymakers to track and understand portfolio performance and to identify and address problems that arise sooner rather than later.

APPENDIX A

JPALS Program History

This appendix provides a summary of key events and milestones for the JPALS effort over time. It supplements what has already been provided in the main text.

Table A.1
JPALS Key Events and Milestones

Date	Event
1992–1995	MNS was based on efforts that started in 1992, by the Assistant Secretary of Defense (ASD) (AT&L) to migrate away from ground-based navigational aids (NAVAIDS) and toward GPS-supported systems. This movement was in line with FAA actions to end production of the Microwave Landing System (MLS) ground stations and start R&D on GPS-based navigation systems
August 1995	MNS for a precision approach and landing capability was approved by the JROC
May 1996	Approval for the JPALS effort to enter Phase 0; Air Force designated as lead agent
October 1997	Initial AoA for JPALS was completed
March 1998	JPALS System Threat Assessment Report (STAR) was initially completed
September 1998	Milestone I DAB review in FY 1998 was not convened because of funding shortfalls; additional program guidance provided by the Deputy Under Secretary of Defense (DUSD) (A&T) directed the continuation of premilestone activities and prototype demonstrations to prove operational capabilities and maturity of the AoA's most promising alternatives
FY 2002	Goal was to reach a Milestone I/II in FY 2002; however, because of continued service funding shortfalls in the FY 2002 POM, this date also was not met
June 2004	USD (AT&L) directed that the original AoA be updated to reflect the effect of technological advances, new capabilities, and improvements to other alternatives that may have arisen since the original analysis, and that applicable adjustments be made in the cost estimates
September 2005	On implementation of the JCIDS process, the Joint Staff directed that the MNS be converted to an ICD, which was approved
November 2005	AoA update was validated by AFROCC
February 2006	JPALS STAR was approved

Table A.1 (continued)

Date	Event
March 2007	JPALS CDD was validated or approved by JROC (only Increments 1 and 2 were approved); Navy designated as lead agent
July 2007	Acquisition Strategy (AS) signed by OSD (AT&L)
2nd Qtr. FY 2007	Navy awarded three contracts from a Broad Agency Announcement with a total value of $12 million; these contracts were intended to stimulate the competitive environment, perform additional sea-based system trade studies, review potential candidate architectures and corresponding technology maturities, and assess potential growth path strategies to future capabilities
June 2008	Defense Acquisition Executive (DAE) conducted DAB; designated JPALS as an MDAP ACAT 1D; approved Milestone B for Increment 1A
July 2008	ADM, AS, and §2366a of Title 10 Milestone B Certification was approved by USD (AT&L)
July 2008	JPALS SDD or development contract was competitively awarded to Raytheon Corporation
July 2008	Following contract award, a GAO bid protest against the contract award was issued with an associated stop work order
September 2008	Bid protest was withdrawn and a contract restart letter was issued
December 2008	DAE approved APB
January 2009	SRR-2
April 2009	IBR
June 2009	SFR
December 2009	PDR
January 2010	Increment 2 CDD was signed
May 2010	Navy chaired Configuration Steering Board (CSB) as a part of a Gate 6 Post PDR (result: no changes to CDD or AS)
December 2010	CDR
2010	Other milestones for 2010: completion of the aircraft performance requirements specification and delivery of the first EDM system to the contractor system integration lab
July 2011	Completed early testing of the GPS receivers onboard LHD-1, which mitigated several program risks before the beginning of formal developmental test
August 2011	Navy-chaired CSB as part of a Gate 6 review
September 2011	Both actions from CSB were successfully closed with the ASN (RDA)

Table A.1 (continued)

Date	Event
October 2011	Program office received EDM 2
November 2011	Program office received Avionics Test Kits (AVTKs) 2-4 in preparation for government testing
December 2011	Contractor also delivered EDM 3 to the contractor system integration lab
February 2012	JPALS Inc. 1A successfully executed a checkout flight with an AVTK-equipped King Air test aircraft against EDM 2 at Naval Air Station (NAS) Patuxent River
May 2012	JPALS Inc. 1A conducted a TRR
June 2012	Commenced integrated test
June 2012	Quarterly exception SAR was being submitted to report a delay in the current estimate for Milestone C of six months from May 2013 to November 2013, resulting in a schedule breach to the APB
October 2012	EDM 5 installation on CVN-77 was completed
December 2012	Sea trials commenced
2012	Raytheon delivered the final five of eight EDMs and the last of the five AVTKs
January 2013	A PDR capturing schedule and procurement cost breaches was received by the MDA
June 2013	Resources and Requirements Review Board (R3B) convened to review the Navy Precision Approach Landing Capability to include re-scope to a single increment

SOURCES: Department of Defense, JPALS Inc. 1 SARs, December 2009 through December 2012; Department of Defense, 2008b; Longuemare, 1996; Department of Defense, 2005.

APPENDIX B

Assessing the "Test Case" Portfolio

In this appendix, we present the results of our assessment of the "test case" portfolio using the chosen portfolio metrics. This test case portfolio was used as our original validation of our portfolio assessment methodology. We later used the methodology to assess the helicopter and satellite portfolios, documented in Chapter Three. We start with descriptors—metrics that describe the composition of the portfolio and its key characteristics and then move on to indicators that provide insight into the portfolio's performance on cost, quantity, and other dimensions. The metrics include a mix of static, "point in time" assessments as well as dynamic measures that consider performance across years. It is important to note that in this chapter, we focus on a discussion of the metrics and their application to the test case portfolio. We do not provide a complete assessment of this sample portfolio or attempt to explain fully the drivers of the observed trends.

Selection of Initial Test Case Study Portfolio

To test the metrics we had identified as relevant to an assessment of portfolio performance, we needed to select a portfolio of programs from the larger portfolio of MDAPs. To aid in efficient data collection, we decided to draw on previous RAND research for OSD that had developed a methodology for anticipating Nunn-McCurdy breaches.[1] This methodology was intended to reduce the approximately 100 MDAPs to a more manageable "watch list" of programs that should be monitored more closely for possible breaches. Previous RAND work used this methodology with 2009 and 2010 data to identify a watch list of programs.

We decided to use this watch list portfolio as our initial test portfolio for a number of reasons. First, there was already a large volume of data that had been systematically collected by RAND analysts for these programs in 2009 and 2010. Second, this portfolio included a variety of programs that are representative of all of the services and different commodity types. This allowed us to see if there were consistencies in how data

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1 Arena et al., 2014b.

were reported across services and commodities and to identify data issues that might affect how portfolio metrics are reported. Finally, these programs could be considered high risk relative to other MDAPs. By selecting this test portfolio as the one in which we intended to observe how our selected metrics reflected this portfolio risk. Another reason that considering this set of programs as a portfolio is that it provides insight into the overall status of a set of programs that are of interest because they are high risk, thus providing analysts with additional information on the overall status of a set of programs that might cause problems in the future.

For the test case portfolio, we selected 32 programs from this watch list that were reported in the SARs for both 2010 and 2012. Table B.1 lists these 32 programs. For each test case program, we collected data on our selected program metrics for 2010 and 2012. We selected these two years to draw on data already collected for 2010 and to compare them with the most current year of reported data (from the 2012 SARs). Although two years is not enough time to detect or diagnose trends, our comparison allowed us to assess our ability to collect the same metrics in different years and provided some insight into the suitability of our methodology for use in portfolio assessment over time.

Table B.1
Initial Test Case Programs

DoD	Air Force	Army	Navy
AMF JTRS	Advanced EHF	Army IAMD	AIM-9X
Chem Demil-ACWA	AMRAAM (AIM-90)	Excalibur	CH-53K Program
HMS (JTRS)	FAB-T Increment 1	JLENS	DDG 100 Destroyer
JSF (F-35)	Global Hawk (RQ-4A/B)	Patriot PAC-3	E-2D AHE
JTN	GPS IIIA		H-1 Upgrades
	JASSM (Baseline)		LCS
	NAVSTAR GPS—Satellite and Control		LHA 6
	Reaper		LPD 17 Class
	SBIRS-High		MH-60S
	WGS		RMS
			Tomahawk (R/UGM-109E)
			Virginia-class (SSN 774)
			VTUAV

SOURCE: Arena et al., 2014b.

Descriptive Metrics

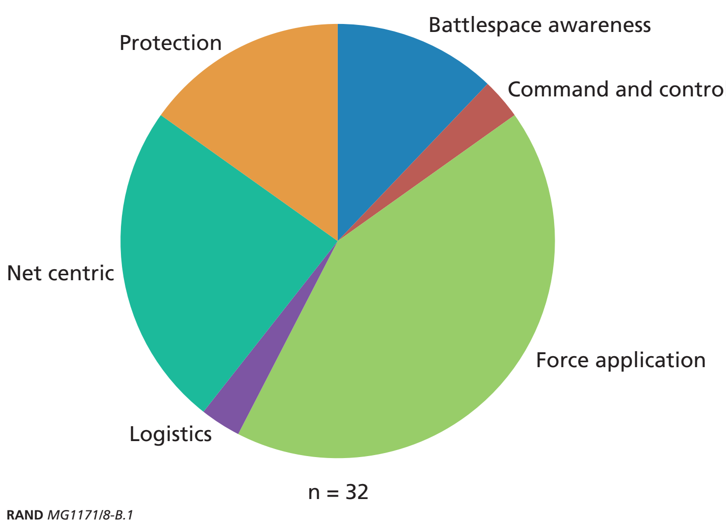
Our first set of metrics included descriptors of the composition of the portfolio. Our test case had 32 total programs, although some of the figures include 33, as we ultimately decided to treat the two blocks of the AIM-9X program separately.[2] The following metrics provide a picture of the portfolio in terms of commodity and type, maturity, program size, and quantity churn.

Portfolio Composition and Latest Milestone Achieved

Figure B.1 shows programs broken down using the DAMIR portfolio categories. This breakdown is useful because it relies on a categorization that most members of the acquisition community are already familiar with and which links directly with DAMIR as an information system with potentially relevant data. The figure shows that the force application category contains the most programs followed by the net centric and protection categories. Two categories, force management and joint training, are omitted because they contain no programs in our test case portfolio.

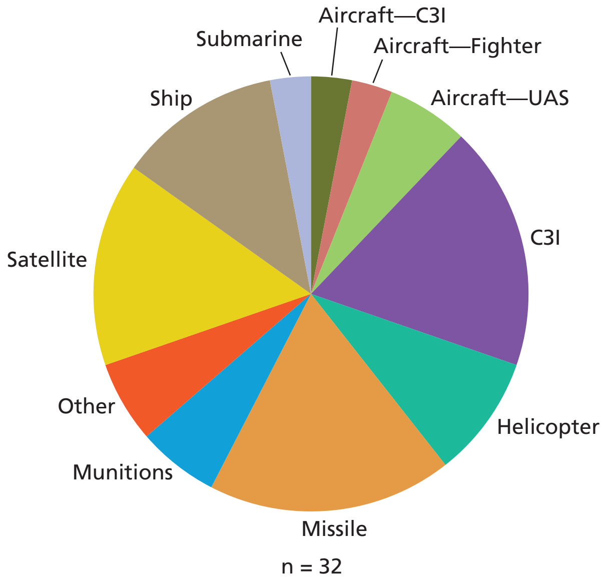
Figure B.2 shows the distribution, by commodity type. Common commodity types include satellites, C3I, missiles, and ships. There are also a good number of aircraft programs, when all types of aircraft are considered together. Both commodity type and the distribution of programs across DAMIR portfolios are the same in the two years we considered in our analysis. This may not be true of all portfolios, however,

Figure B.1
Programs, by DAMIR Portfolio



2 We treated the two blocks separately because they have different PNOs.

Figure B.2
Programs, by Commodity Type, 2010 and 2012 (Same Composition Both Years)



RAND *Mg1171/8-B.2*

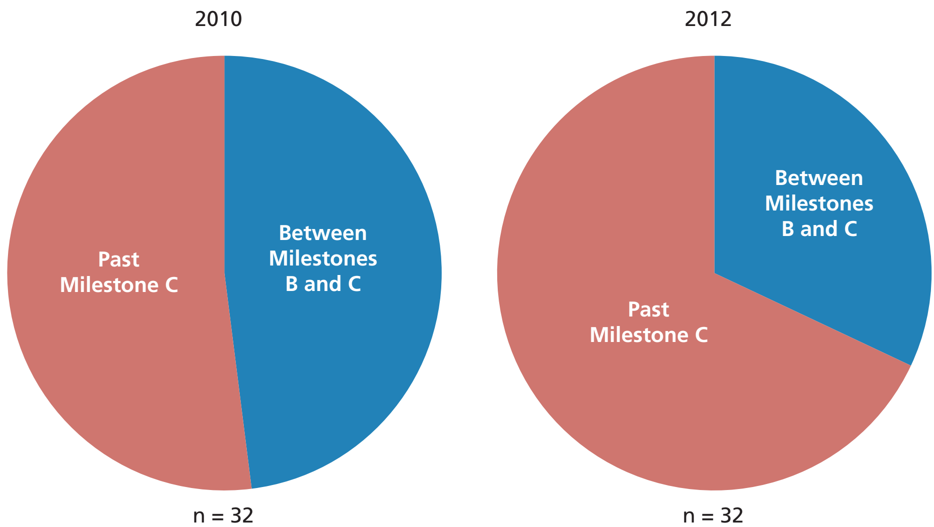
especially when longer time periods (in which we are more likely to see programs enter and exit a portfolio) are considered.

Descriptors can also give insight into the maturity of the portfolio at any given point in time as well as over time. Figure B.3 compares two pie charts, one for 2010 and one for 2012. Each pie chart characterizes the portfolio by illustrating the number of programs that have passed Milestone C and the number between Milestones B and C. Unlike the previous two descriptors, these distributions do not stay the same over time. A comparison of the two graphs clearly shows that more programs have passed Milestone C in 2012 (unsurprisingly) than in 2010. This suggests that the 2012 portfolio is more mature than that in 2010.

Program Size

Another metric of interest for policymakers is total program dollar value, which is the median size in monetary terms of programs in a portfolio. As noted above, policymakers may be more concerned about breaches and such problems as unit cost growth or volatility in quantity when programs are large and involve more money. As we considered total program value for the test case portfolio, we faced a challenge posed by a significant outlier, the F-35 program. This program is considerably larger than all others included in the portfolio and so significantly skews the program value portfolio metric. To address this, we calculated the total program value metric both with and without the F-35. The difference is reasonably substantial and the resulting metrics provide us

Figure B.3
Programs, by Last Milestone, 2010 and 2012



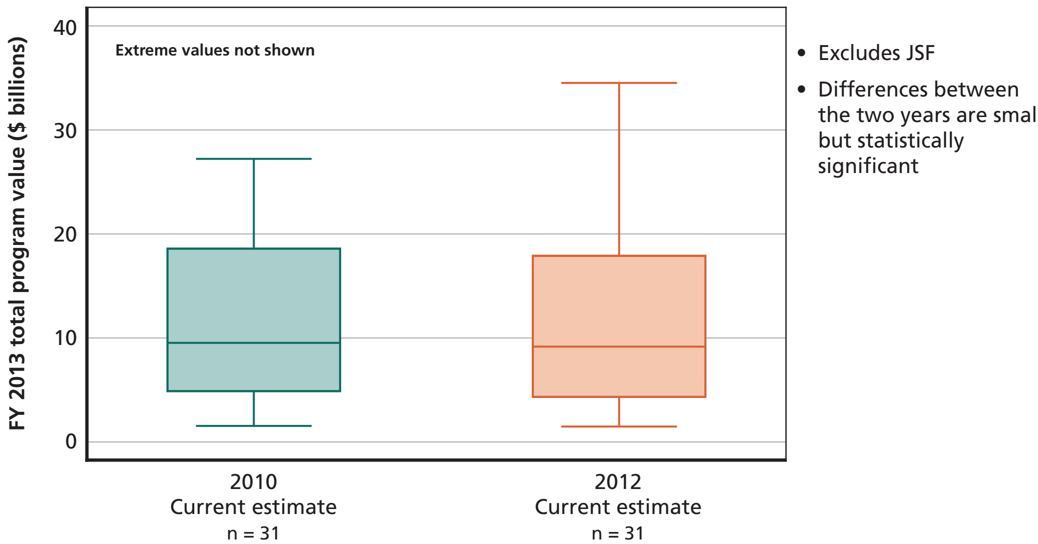
RAND *Mg1171/8-B.3*

with two slightly different types of information. The metrics including the F-35 tell us the "true" median, range, and standard deviation of total program values, whereas metrics that exclude this outlier provide a more realistic assessment of the size and size distribution of programs in the portfolio.

Figure B.4 shows the box plot for total program value excluding the F-35. There is a statistically significant decline in the total program value between 2010 and 2012; however, Cohen's D tells us that the size of this decline is effectively zero and not substantively meaningful. This suggests that for the most part, the overall program value of our test case portfolio remains the same across the two years. Once we include the F-35, this affects the median value and standard deviation but, notably, not our conclusion that there is effectively no change in program value across the two years. This is not all that surprising, as the same programs are included in each year or sample.

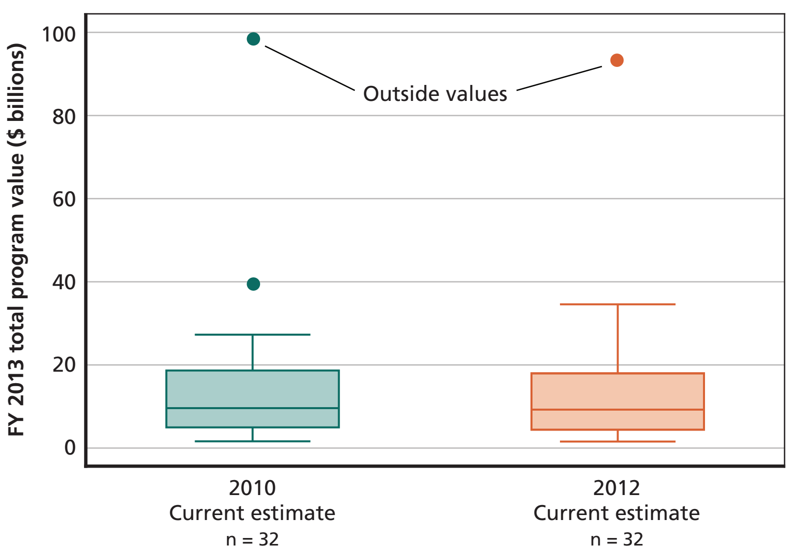
In addition to excluding the F-35, Figure B.4 also excludes "outside values," defined above as those points that lie more than 1.5 times the interquartile range from the rest of the data. Figure B.5 includes these values and is intended to illustrate the effect of these additional outliers on the graphical representation of program value. Although excluding these outside values would further reduce the median of program value, we chose to leave these values in, erring on the side of inclusion rather than risking overmanipulation of the data.

Figure B.4
Total Program Value, Excluding the F-35, 2010 and 2012



RAND *MG1171/8-B.4*

Figure B.5
Total Program Value, with Outside Values, 2010 and 2012



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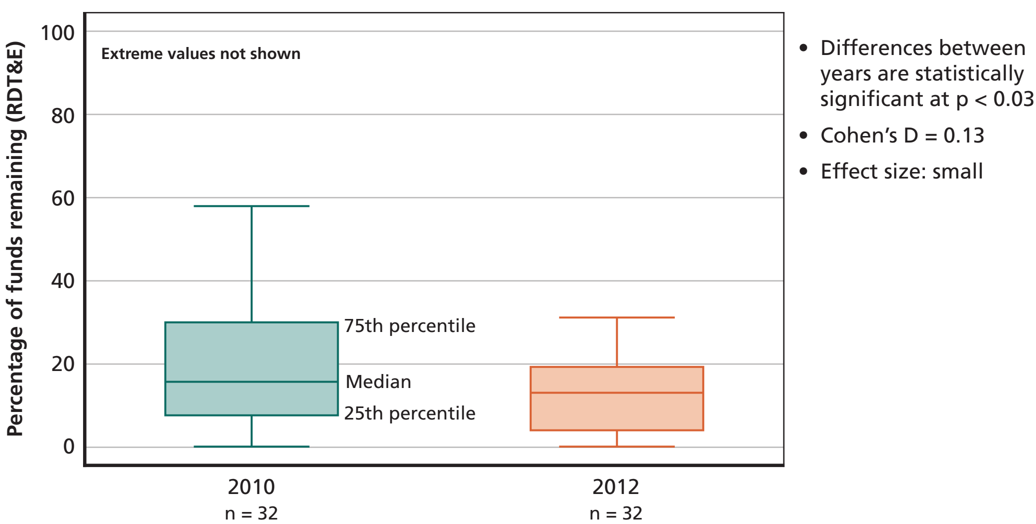
Percentage of Funds Remaining

Program maturity is another indicator of portfolio risk; as a portfolio matures, its sources of risk change. When a portfolio has many programs that have not yet reached Milestone B, the majority of the risk is associated with program development. When a portfolio has many programs that are past Milestones B and C, the majority of risk is associated with procurement. Understanding this difference can help an analyst describe the risk inherent in the portfolio and provide context for the portfolio's performance on other dimensions. Above, we considered portfolio maturity using the number of programs past Milestones B and C. Another way to assess program maturity is to consider the percentage of funds remaining, as this indicates how much of the program budget has been spent (and therefore how close the program is to completion). Figures B.6 and B.7 offer two perspectives on this, one that uses RDT&E funds and one that uses procurement funds. We again use box-and-whisker plots to visualize the changes between these two portfolios on these two metrics over time.

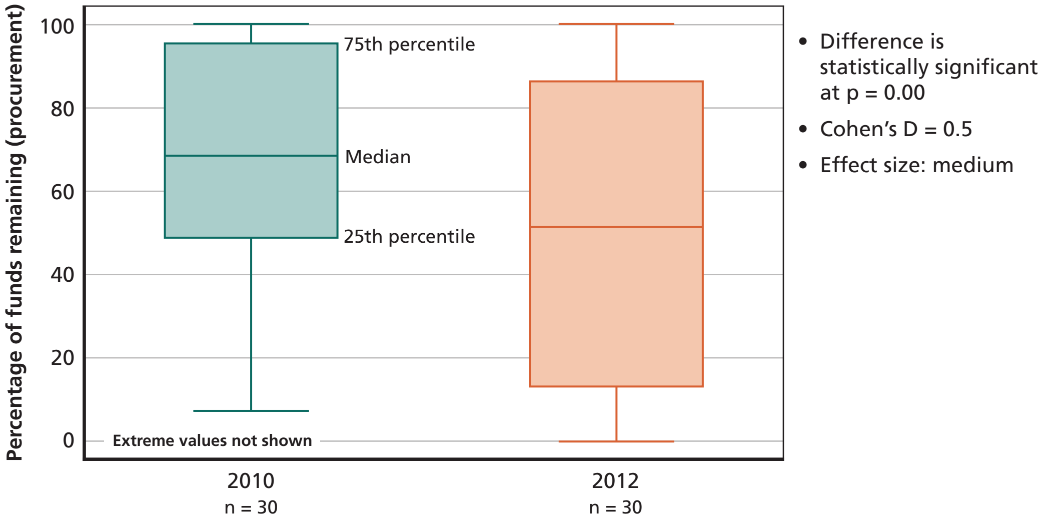
Figure B.6 shows the percentage of RDT&E funds remaining in each of the two years. The graph suggests a small decrease in funds remaining between 2010 and 2012, which is not surprising given that only two additional years have passed. This change would also be consistent with a gradual maturing of the portfolio over time. A t-test confirms that this difference is statistically significant (or that the change is a real change in the trend and is not simply noise in the data); Cohen's D, however, indicates that the effect size is small. This graph then generally confirms our sense that the portfolio in 2012 has become more mature but also suggests that this change, at least as measured by remaining RDT&E funds, is fairly small.

Figure B.6
Percentage of Funds Remaining, RDT&E, 2010 and 2012



RAND *MG1171/8-B.6*

Figure B.7
Percentage of Funds Remaining, Procurement, 2010 and 2012



RAND *MG1171/8-B.7*

Figure B.7 shows the percentage of procurement funds remaining in each of the two years. It also suggests a decline in the median percentage of funds remaining (a sign of program maturity) but also a sizeable increase in the distance between the 25th and 75th percentiles or the spread of the data. The two trends together suggest that between 2010 and 2012, some programs underwent a large reduction in their percentage of procurement funds remaining (in other words, they spent a large amount of their procurement budgets), whereas others experienced only a small change. A t-test suggests that this effect is statistically significant and Cohen's D tells us that the effect size is medium and substantively meaningful. Of course, it is also worth considering the starting points for the two metrics. Although most programs had already spent more than 50 percent of their RDT&E budget in 2010 (the median, in fact, was below 20 percent remaining), the median for procurement funds remaining was about 70 percent. Therefore, there was more room for a more substantively meaningful decline when considering only procurement funds. The difference in starting points makes sense, given the fact that RDT&E funds will be spent early in a program life cycle, but procurement funds may not be spent until later.

Portfolio Churn: Quantity Changes

Turning to an assessment of changes in quantity, it is important to keep in mind that a change in quantity does not, in itself, indicate a problem in the program. Rather, it may suggest an increase in demand or some other explainable change. As an example, the Tactical Tomahawk experienced a sharp increase in quantity during the conflict

in Libya when it was in much higher demand. This did not suggest a true problem in the program but instead the nature of U.S. military activity and requirements. However, changes in quantity demanded or procured can often lead to instability in the program that increases the risk for cost growth or other problems. Figure B.8 uses a bar chart to highlight programs that experienced a change in quantity between 2010 and 2012. One key observation is that not all programs experience changes in quantity. Our churn metric measures the number of programs with any changes in quantity in a given year. This metric provides additional insight: 18 out of the 33 programs (again counting the AIM-9X variants as two separate programs) have some change in quantity in each of the two years, although it is not the same programs experiencing quantity changes in each of the two years. Figure B.8 identifies programs with large changes in quantity. On the positive side, SBIRS-High, LHA 6, and JTRS HMS experience an increase in 2010, whereas PAC-3 and LHA-6 experience increases in 2012. Most of the negative changes also occur in 2012, namely, to the JLENS, Global Hawk, and AMF JTRS programs.

Performance Metrics

Nunn-McCurdy and Acquisition Program Baselines Breaches

Another set of metrics of interest to policymakers and analysts conducting a portfolio assessment counts the number of both Nunn-McCurdy and APB breaches. Figures B.9 and B.10 show the number of each type of breach, comparing 2010 and 2012. Figure B.9 shows number of programs with significant and critical breaches in the current and original APUC and PAUC. Figure B.10 shows the number of new APB breaches, by type, in each year. It appears that there are somewhat fewer APB and Nunn-McCurdy breaches in 2012 than in 2010. However, when we assess the statistical significance of this difference, using a t-test as described in Chapter Two, we find that the difference is not statistically significant. This means that the change in the number of breaches between the two years could just be due to chance and does not represent a meaningful change over time.[3]

Unit Cost Growth

The next set of metrics that we consider focuses on unit cost growth—a metric of significant importance and interest to policymakers. We assess unit cost growth in several ways, first looking at the distribution of growth in APUC and PAUC in 2010 and 2012

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[3] The t-test in this case compares the distribution of breaches (numbers and types of breaches) in 2010 and 2012 to determine if the two samples appear to come from a single or two different distributions. Because the result is not statistically significant, we cannot reject the null hypothesis that there is no difference between the two years or say for sure that the small change we do observe is not due to chance.

Figure B.8
Percentage Change in Quantity Versus Baseline, 2010 and 2012

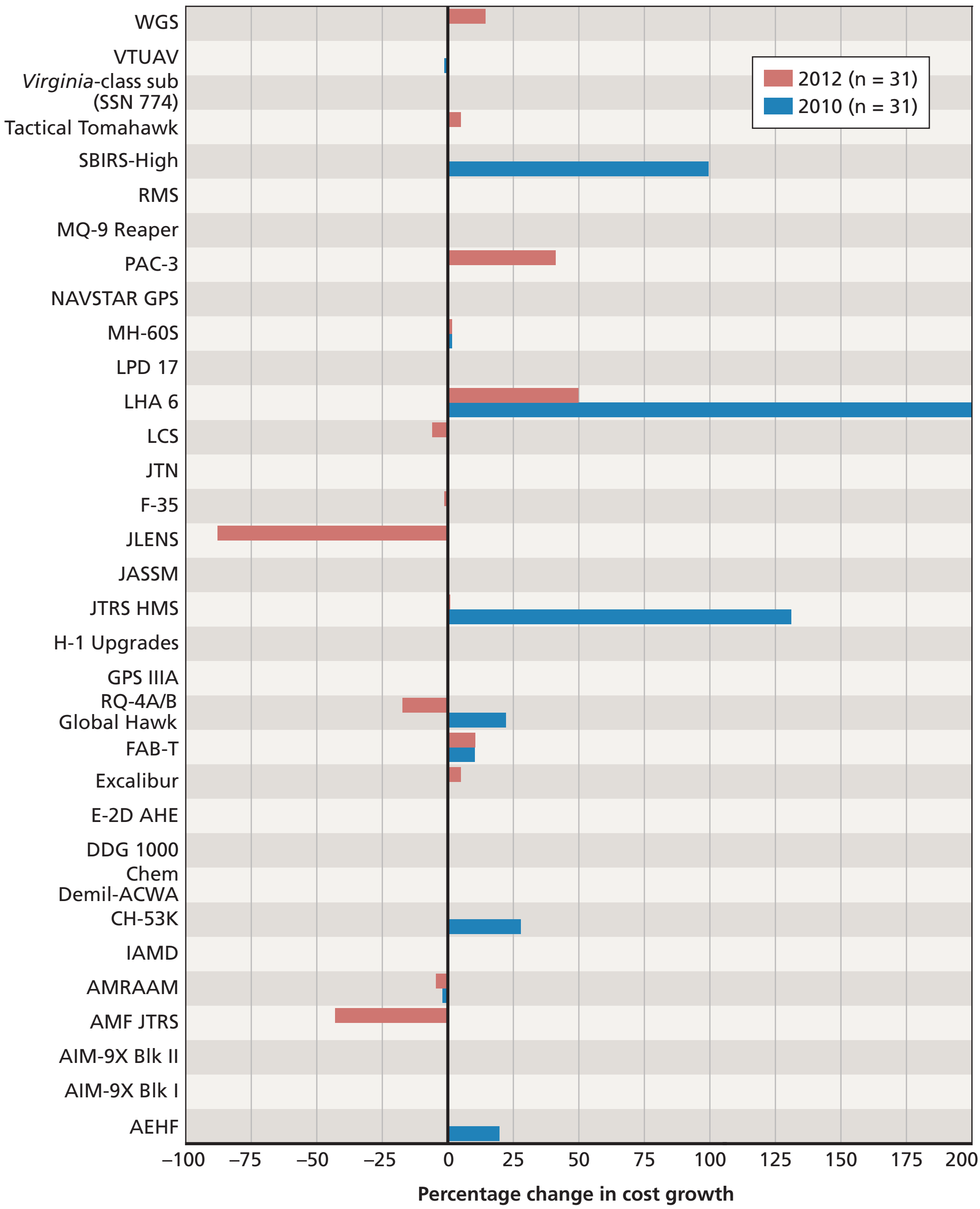

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Figure B.9
Nunn-McCurdy Breaches, 2010 and 2012

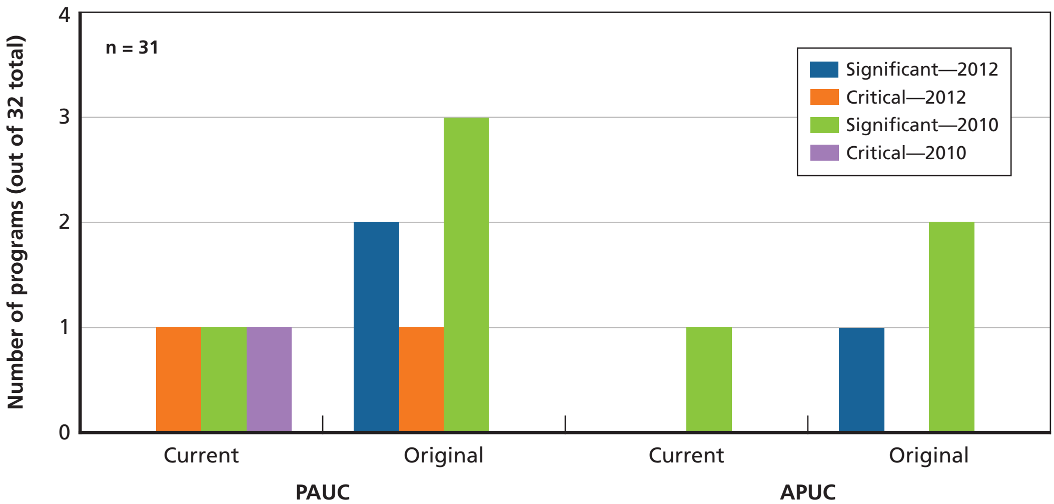

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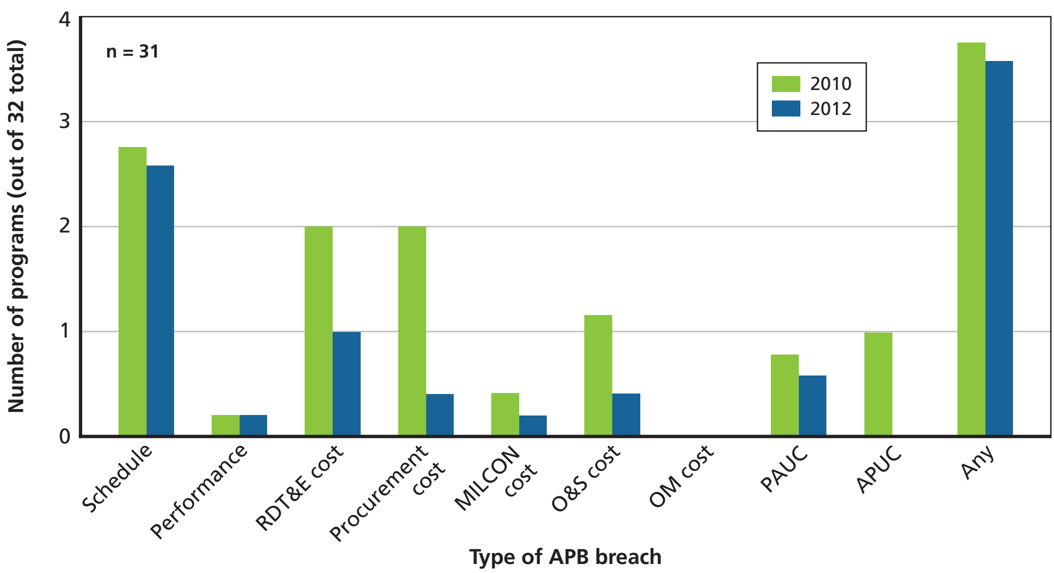
Figure B.10
Number of APB Breaches, 2010 and 2012



NOTE: Difference in number and types of breaches between 2010 and 2012 is not statistically significant at p = 0.2.

RAND *MG1171/8-B.10*

across all programs in the portfolio and then comparing the cost growth in 2010 and 2012 at an aggregated portfolio level.[4]

Starting with the unit cost growth distribution charts, Figures B.11 and B.12 show the percentage change in unit cost for the PAUC and the APUC, using the current baselines in 2010 and 2012, and reveal significant variability in cost growth across programs. Programs with especially high cost growth include the Global Hawk, FAB-T, JLENS, VTUAV, and *Virginia*-class submarine. It is worth noting that we have excluded data for the JLENS program from 2012 for PAUC because it is a significant outlier with very high cost growth, which distorts the rest of the graph. Also, other programs appear to have missing data. These missing observations are programs for which we could not collect cost growth data in the years of our analysis. As noted above, there may be several reasons for missing data points, including rebaselining, program completion, program splits that result in new blocks or component programs, or the nature of the program itself. For example, Chem-Demil-ACWA is essentially a service, not a physical product, thus precluding the use of metrics derived from quantities, including unit cost growth.

A visual review of the two graphs suggests somewhat lower cost growth in 2012 than 2010. However, this difference requires additional investigation and testing before we can draw any conclusions about portfolio status.

The next step in our analysis of unit cost growth is to compare the percentage unit cost growth in the PAUC and APUC directly for each of the two years in our analysis to explore whether there are statistically significant differences in this metric at the portfolio level. For this, we use box-and-whisker plots, the interpretation of which was described in Chapter Three. The shaded box in each case contains 75 percent of the data and the line within each box the median value. Looking at this graph for the APUC (Figure B.13), it appears that median cost growth declined between 2010 and 2012. A t-test confirms that this difference is statistically significant (resulting from a real change in the trend, not simply noise in the data), although our Cohen's D test suggests that the effect size is substantively small. Still, the graph suggests some change in unit cost growth and also a more narrow spread or variance in the data in 2012. However, it is important to note that this graph does not tell us anything about the drivers of this change, whether they reflect better program management or simply a more mature portfolio of programs. The answers to these questions would be part of a comprehensive portfolio assessment but are outside the scope of this appendix.

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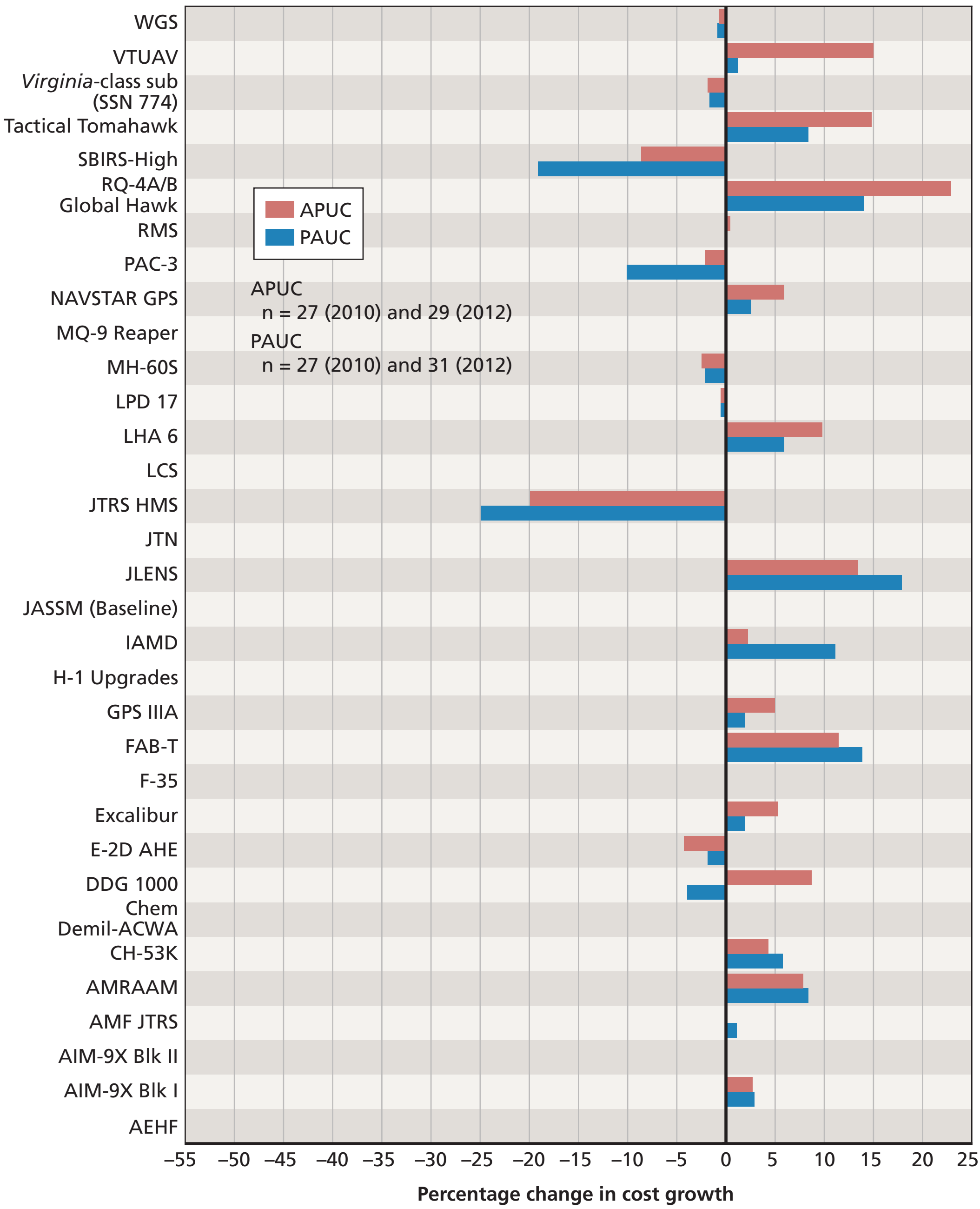
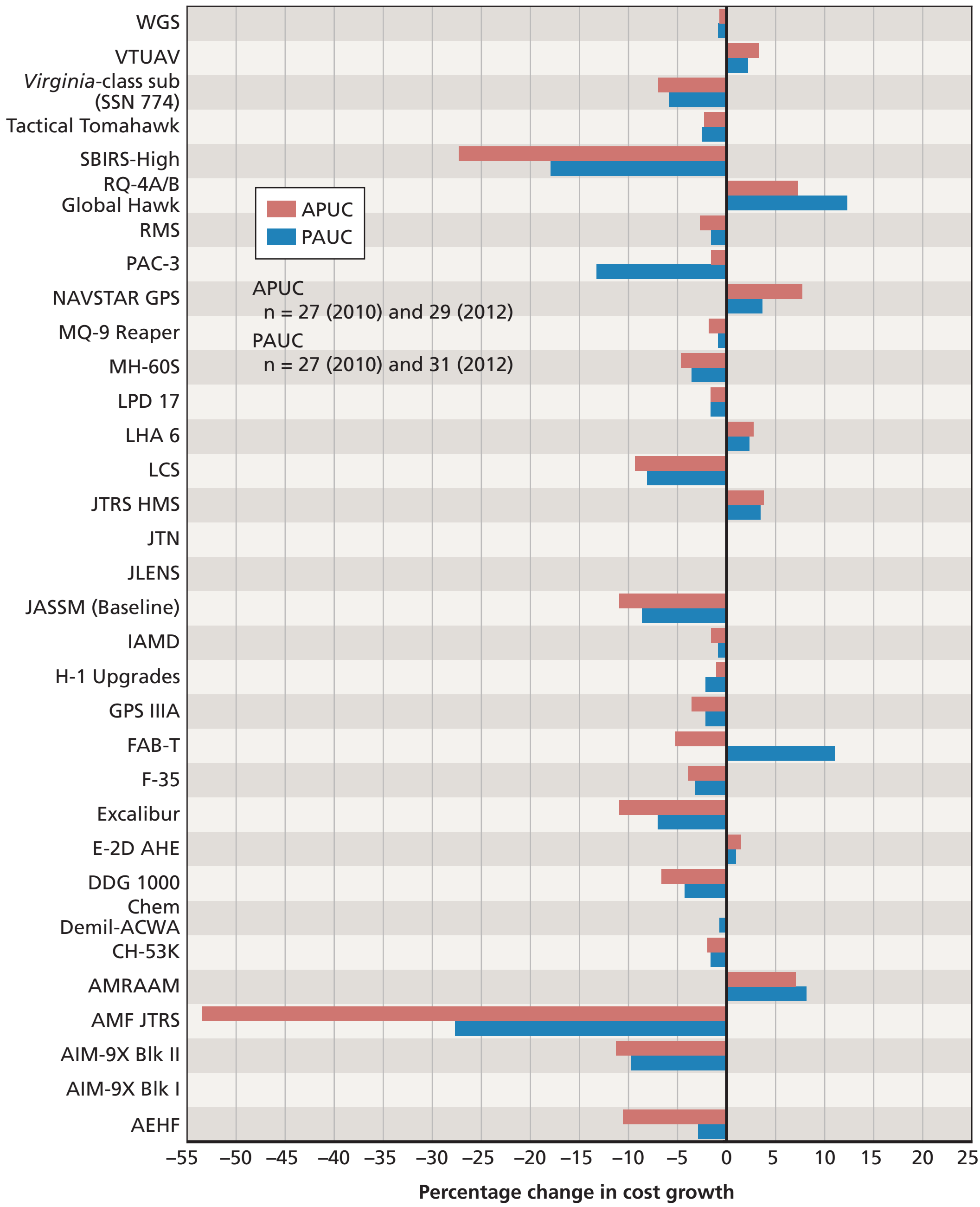
[4] APUC is calculated by dividing total procurement cost by the number of articles to be procured. Total procurement cost includes flyaway, rollaway, sailaway cost (that is, recurring and nonrecurring costs associated with production of the item such as hardware/software, systems engineering [SE], engineering changes and warranties) plus the costs of procuring technical data (TD), training, support equipment, and initial spares. PAUC is calculated by dividing the Program Acquisition Cost by the Program Acquisition Quantity. The PAUC and APUC are the subject of the Unit Cost Reports (UCRs).

Figure B.11
Percentage Cost Growth Against Current Baseline, 2010



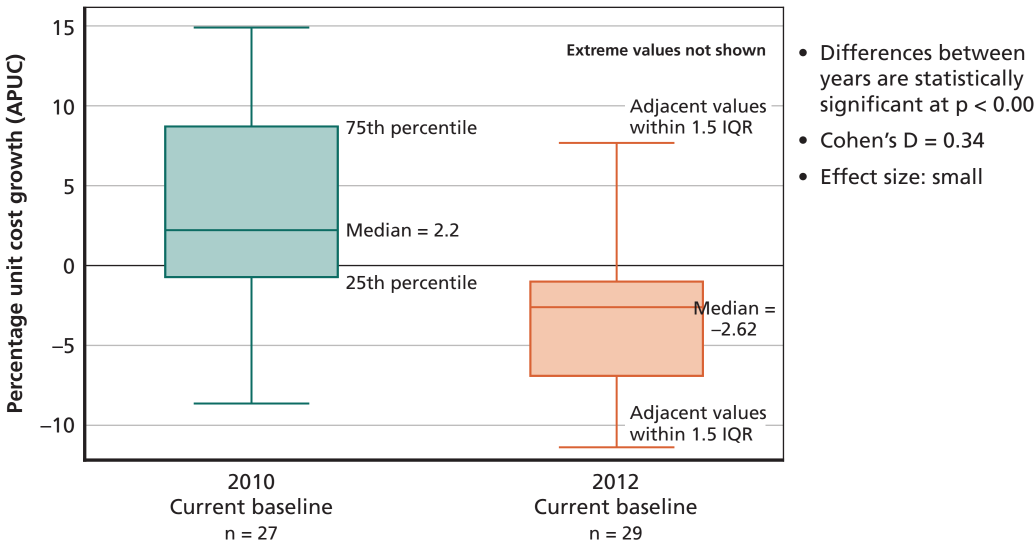
RAND *MG1171/8-B.11*

Figure B.12
Percentage Cost Growth Against Current Baseline, 2012



RAND *MG1171/8-B.12*

Figure B.13
APUC percentage Unit Cost Growth Current Baseline, 2010 and 2012



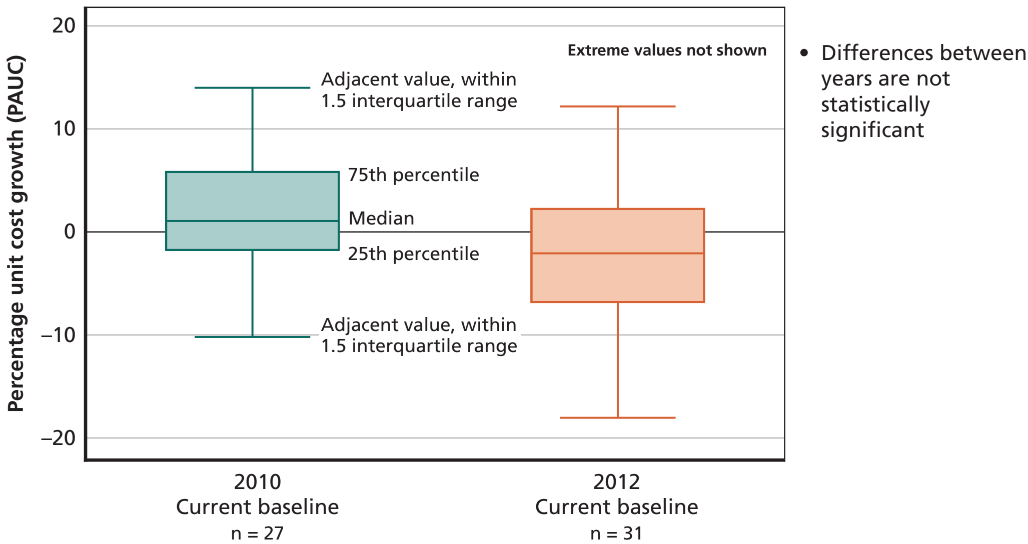
RAND *MG1171/8-B.13*

Moving to the PAUC, Figure B.14 shows the percentage change in PAUC between 2010 and 2012 using the current baseline. Although the graph does suggest a decline in unit cost growth, a t-test suggests that this difference is not statistically significant. Therefore, we cannot say for sure that the change that we observe in PAUC is not simply due to chance or that there is any evidence of a real change in portfolio status based on these results. If we were interested in completing a full assessment of the two portfolios, we would want to dig further into why we find a statistically significant change only for the APUC.

In addition to analyzing percentage change in unit cost using unweighted data, we also explored whether weighting unit cost growth by program size affected the result of our analysis. This weighting by program size may be important because cost growth in large programs may be more damaging to the overall portfolio than cost growth in smaller programs. Although the weighting does change the calculated median and mean values, it does not affect the general observations above. We find substantively small changes in percentage unit cost growth that are statistically significant when considering the APUC and not statistically significant when considering only the PAUC.

Another important iteration on our cost growth analysis looked at cost growth using original rather than current baselines. Looking at unit cost growth using current baselines can be misleading if programs have recently rebaselined, as this may make their cost growth appear artificially low. In our test case sample of programs, this is most likely to be problematic for programs that rebaseline between 2010 and 2012,

Figure B.14
PAUC percentage Unit Cost Growth Current Baseline, 2010 and 2012



RAND *MG1171/8-B.14*

as this will affect their apparent cost growth in 2012 and bias our assessments of how portfolio metrics have changed over time. Table B.2 lists the programs that rebaselined between 2010 and 2012, thus affecting our assessment of unit cost growth within the test case portfolio over time, along with a reason for the rebaseline. The table shows that the rebaselining issue will affect a large number of our programs and so could have significant implications for our overall assessment if not considered more carefully.

To address this possible confounding factor, we also study unit cost growth for the APUC and the PAUC using the original baseline, which for most programs is constant over the entire time period. A few programs have new current *and original* baselines between 2010 and 2012.[5] Looking at original baseline cost growth will not address or correct for the effects of rebaselining for these programs.

Figures B.15 and B.16 show the percentage unit cost growth for APUC and PAUC using original baselines. The graphs look similar to those using the current baseline, and the general insights offered by each graph are largely, but not entirely, the same. The graph for percentage change in APUC suggests a decline in unit cost growth between 2010 and 2012 that is statistically significant. Calculating Cohen's D

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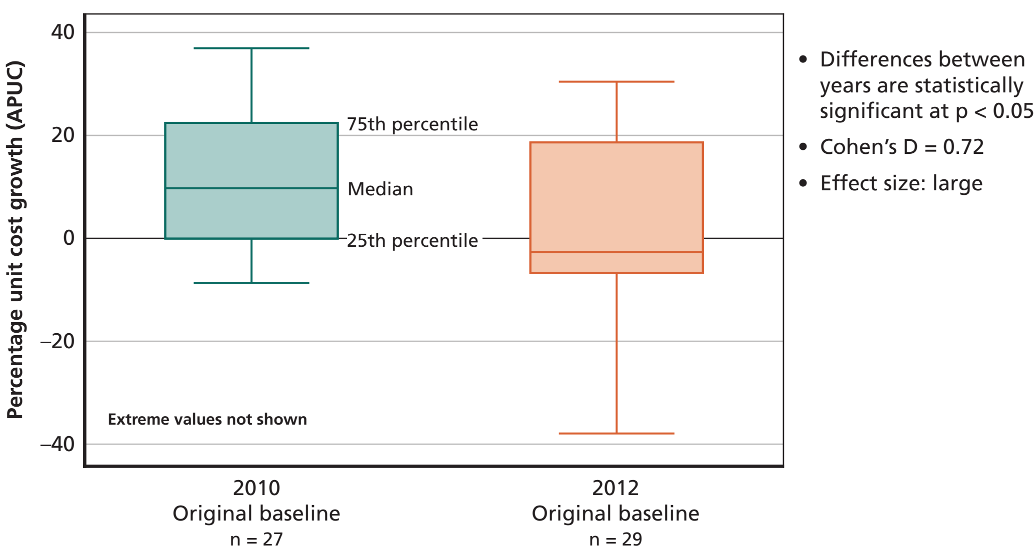
[5] An original APB may be revised only in the event of a critical breach, which entails, for the original APB, an increase of at least 50 percent over the original APUC or PAUC. However, the current APB may be changed for the following reasons: at milestone, full-rate production, and full deployment decisions; at a major program structure approved and fully funded by the MDA; or if the MDA concludes that fact-of-life program changes deem management to the existing baseline impractical. Programs are explicitly prohibited from rebaselining simply to avoid a breach. DoDI 5000.02, January 2015.

Table B.2
Programs Experiencing a Rebaseline Between 2010 and 2012

Program	Current Baseline	Reason for Rebaseline
AEHF	2012	Established SV5-6 as a subprogram
Army IAMD	2012	APB reflects increased production quantity and added systems
CH-53K	2013	O&S breach, quantity changes, and beyond-threshold increases in PLCCE
E2-D AHE	2013	New APB for full rate production (FRP)
Excalibur	2012	Program restructured due to Nunn-McCurdy breach
JSF/F-35	2012	APB reflects development program restructure in 2011
LHA 6	2012	APB updated to include LHA 7
LPD 17	2011	APB change to reflect LPD 26 and LPD 27
Reaper	2012	Milestone C approved, new production APB
RMS	2012	APB updated to reflect new KPPs from the CDD
SBIRS	2013	Established GEO 56 Block Buy program
Tomahawk	2011	APB reflects increased procurement quantities (Libya replenishment)
VTUAV	2011	Program restructured due to APUC breach

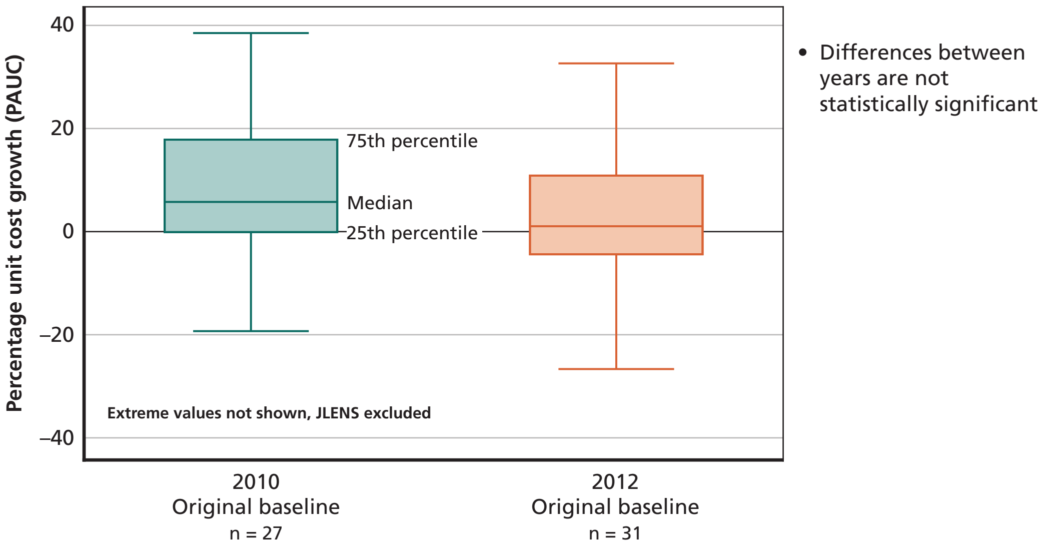
NOTE: Programs in blue have a new original and current baseline in the indicated year.

Figure B.15
Percentage Change in APUC, Original Baseline, 2010 and 2012



RAND *MG1171/8-B.15*

Figure B.16
Percentage Change in PAUC, Original Baseline 2010 and 2012



RAND *MG1171/8p-B.16*

suggests that this change is substantively meaningful and large, unlike the small effect observed for the current baseline graph above. This suggests that rebaselining does have an effect on our assessment of unit cost growth. In the case of the APUC, focusing on the current rather than the original baseline may underestimate the negative change in unit cost growth between 2010 and 2012. However, in the case of the PAUC, even looking at the change using the original baseline does not suggest a significant change in unit cost growth between the two years. Although the median does decline slightly, this difference is not statistically significant and so could just be due to chance or noise in the data.

Summary

In our analysis of the test case portfolio, we focused primarily on describing and documenting a set of metrics and visualizations that can be used in a subsequent assessment of how and why the test case portfolio has changed over time. Although we do not conduct a comprehensive analysis in this chapter, our visualizations appear to provide some evidence of a gradually maturing portfolio: More programs have passed Milestone C, and programs appear to have spent more of their RDT&E and procurement funds. There has been a small but statistically significant decrease in unit cost growth when APUC is considered alone and an apparent drop in the number and types of breaches between the two years (although this change was not statistically significant).

We also observed some decrease in total funds remaining, particularly for procurement, and some churn in quantity in both years of the analysis. These trends would be consistent with a maturing portfolio and may suggest some improvement over the two years of our analysis. However, before making any strong statements about the status of the test case portfolio in the two years of our analysis or any changes over time, we would need to conduct a more in-depth assessment to explore why we see the changes that we do. It is important to note that the conclusions and inferences that we can draw from our analyses are limited by that fact that our current assessment compares only two years of data and a relatively small number of programs.

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The authors examine the cause of the Joint Precision Approach and Landing System (JPALS) major defense acquisition program Nunn-McCurdy unit cost breach and document a methodology that can assess and summarize the overall performance of an acquisition portfolio at a point in time and over several years. In January 2014, the Navy informed the USD (AT&L) that both the average procurement unit cost and the program acquisition unit cost for the JPALS Inc. 1A program exceeded critical thresholds against both the original baseline and the current baseline, triggering the Nunn-McCurdy process, which is statutorily required by the 2009 Weapon Systems Acquisition Reform Act legislation. The team used official primary source documentation, interviews, and trade literature to assess and document the reasons for the critical cost growth. The methodology developed to assess portfolio performance included identifying objectives, choosing a portfolio type, selecting data and metrics, addressing data anomalies, and calculating and visualizing metrics. The authors applied the methodology to two sample portfolios—helicopter and satellite—from 2002 to 2012. They considered cost and schedule performance over time, reasons for changes in the portfolios' composition and maturity, the drivers and implications of rates of program spending, the percentage of funds remaining, the potential for future cost growth, the effects of rebaselining, and trends in associated Nunn-McCurdy breaches.

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